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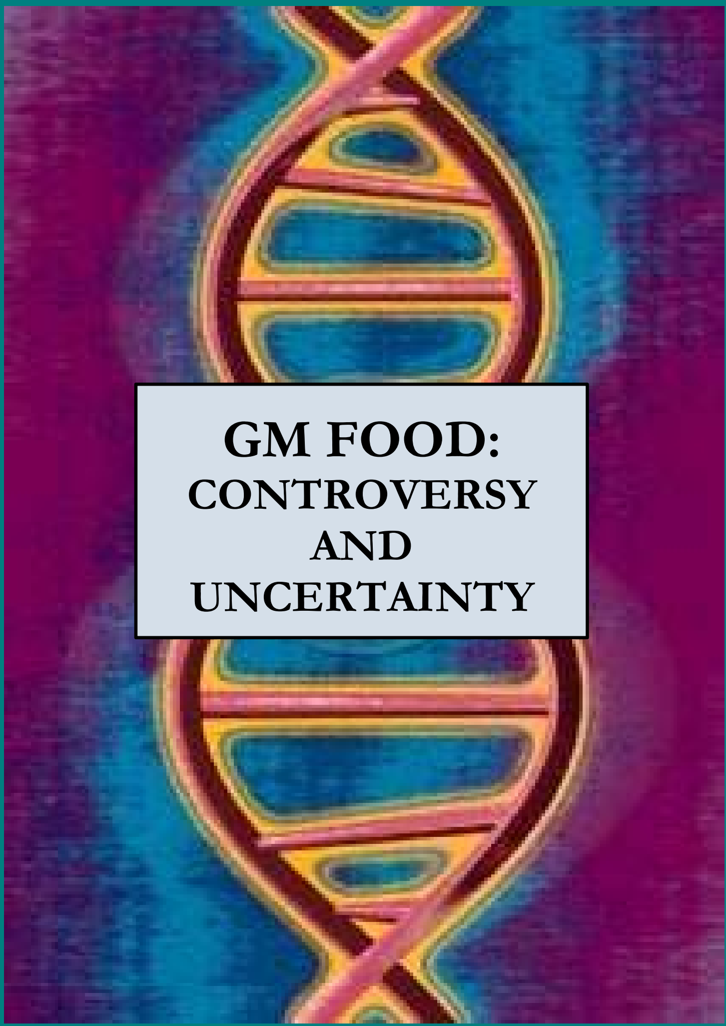

GM FOOD: CONTROVERSY AND UNCERTAINTY

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Preface:

This thesis is about the debate on genetically modified (GM) food. For the uninitiated reader, I have made an appendix (appendix 1) where I explain some basic concepts and principles of the technology involved. Here I have also described some of the most common GM food products today.

The thesis is written as part of an internship at the International Centre for Integrative Studies (ICIS) in Maastricht, the Netherlands. This is a young research institute that focuses on sustainable development and novel forms of decision-support.

I wish to thank Marjolein van Asselt for giving me the opportunity to be a part of the every-day life of this institute, which has given me invaluable hands-on experience with science-in-the-making, and for tough but appreciated criticisms. Also, I want to thank Roland Bal and Jessica Mesman for their reflected guidance and emotional support, Kristin for many fruitful discussions and for being who she is, the staff at ICIS for all the 'vlai' and the other ESST students in Maastricht for making this an unforgettable experience.

Synopsis:

GM food is one of the most hotly debated results of modern technology today. Often, the resistance against it is characterised as a result of ignorance and superstition, with an assumption that increased awareness of the 'facts' will resolve the debate. In this thesis, I will counter this assumption:

Firstly, on the grounds that the 'facts' are pointing in different directions, and that this can be said to be the result of fundamentally different ways of looking at the problems involved.

Secondly, because the potential impact of GM food on society, the environment, human health and human well being is a *complex* issue, and inherent in all complex issues is uncertainty.

These assertions are based on an analysis of a broad selection of issues common in the GM food debate in terms of sources of uncertainty. These are classified in a recently developed taxonomy[1], which also forms the foundation for the analysis.

The focal point of this thesis is not to decide who is right or wrong, but rather to understand why there is disagreement in the first place. Thus, the debate is described in a fundamental sense, looking behind the 'facts'.

This thesis is also an elaboration on the above-mentioned taxonomy of sources of uncertainty. Changes have been made to adjust for the particularities of the empirical setting, and each source of uncertainty is given a more extensive definition.

Keywords

Genetic modification, food, uncertainty, controversy, facts, values

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[1] van Asselt, M. B. A. 2000; 3A: 7-9

Chapter 1: Introduction

Modern biotechnology and genetic modification have given unprecedented possibilities to introduce new traits in plants and animals. Whereas conventional breeding methods rely on close species-relations, recombinant DNA (rDNA) technology has made it possible to insert genes from any species into the genome of any other species, such as from a bacterium into a plant. This potentially represents large economic and other benefits, such as crops that grow faster and give higher yields, and food that is tastier, more nutritious and lasts longer on the shelves.

Despite of this, there has been strong public resistance against the use of this technology on organisms intended for food. Often, this resistance is characterised as irrational or ignorant, with a call for more education. This is contrary to the conclusions of several studies. For instance, an analysis of the Eurobarometer on Biotechnology (1996) showed that the more 'educated' part of the respondents, as measured by a set of ten questions on biotechnology, also were more confident in their attitudes towards it. However, *both* positive *and* negative attitudes increased with better education.[1]

The call for more education implicitly assumes that 'sound science' provides the answers needed. However, this is a relatively young technology, where many of the proposed possibilities and implementations lie in the future. Many believe there are large uncertainties when it comes to potential effects on society, the environment, human health and human well-being, particularly in the long run.

In concordance with this view, I will argue in this thesis that the potential impact of GM food is a *complex* issue, and inherent in all complex issues is uncertainty[2]. This means that there are no straightforward answers.

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[1] Hviid Nielsen, T. 1998. See also ESRC Global Environmental Change Programme 1999
[2] van Asselt, M. B. A. 2000; 1: 1-2

Aims and objectives

For a long time I have wanted to take a closer look at the GM food debate – partly out of interest in biology and biotechnology, but mostly because I so often have been frustrated by participants in the debate throwing 'facts' at each other with no visible result. Therefore, in the spirit of Science and Technology Studies (STS), I have wanted to look beyond the 'facts', to what lies underneath such diverging claims.

To this end I have collected and analysed a broad selection of arguments common in the GM food debate in terms of sources of uncertainty, as described in a taxonomy developed by van Asselt (2000) [3].

So far, this taxonomy has not been tested in an empirical context to any extent, and is originally formulated in brief terms. Thus, one of my goals has also been to define and refine this taxonomy as a tool for future empirical settings.

Both through the collecting and categorising of controversial issues, as well as through the analysis in terms of sources of uncertainty, I have wanted to identify which controversial issues that can be said to be more problematic than others. This is the ultimate goal of this thesis: to provide a basis for future assessments of the effects of GM food, in terms of where the focal point of managing the controversy has to be directed.

[3] Ibid.; 3A: 7-9

Chapter 2: Theoretical Framework and Methodology

In this thesis, I have mainly used theories on uncertainty from van Asselt (2000) and STS literature, as well as principles and a methodological stance common within the field of STS.

The most important contribution from van Asselt's work for this thesis is the taxonomy of sources of uncertainty, which is also the first topic of this chapter:

Sources of uncertainty

Van Asselt (2000) proposes a taxonomy over sources of uncertainty that is built upon a recent inventory of classifications of uncertainty[1], as well as a review of scholarly uncertainty literature[2]. One of the stated aims with this taxonomy is to explain *why* disagreement and subjectivity are likely to occur in science. The sources of uncertainty is thus a way of looking beyond the 'facts' of science, and instead bring to light what makes such 'facts' disputed[3]. This taxonomy aims to be *generic,* in that it should be applicable to all contexts[4]. This means that all issues that involve uncertainty should be possible to trace back to one or more of the sources in the taxonomy.

The taxonomy is situated within the larger context of decision-support, with a perspective that can be characterised as 'supply-driven'. This means that the issue of decision-support is addressed from the view of the scientists and analysts, as opposed to from the decision-makers and stakeholders (characterised as demand-driven).[5]

In the analysis in chapter 4 and 5, I will give a thorough explanation for each of the sources in this taxonomy. However, as a preparation, I will briefly describe them here.

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[1] van der Sluijs, J. P. 1997
[2] van Asselt, M. B. A. 2000; 3A: 8
[3] Ibid.; 4: 10
[4] Ibid.; 2: 7
[5] Ibid.; 1: 4

According to van Asselt (2000), at the highest level of aggregation, there are two main sources of uncertainty: variability and lack of knowledge[6]. Variability is also referred to as 'objective', 'stochastic', 'external' or 'random' uncertainty, and is viewed as an attribute of reality. Lack of knowledge is referred to by others as 'subjective', 'informative', 'secondary' or 'internal' uncertainty, or 'incompleteness of the information', and is viewed as a property of the analysts performing a study and/or our state of knowledge. Uncertainty thus has both an ontological (variability) and an epistemological (lack of knowledge) dimension in van Asselt's taxonomy. Variability can be seen as a source of lack of knowledge, as it makes perfect, certain knowledge anyhow unattainable.

Both variability and lack of knowledge can be divided into several subcategories. These are:

Variability:

- Inherent randomness of nature: the chaotic and unpredictable nature of natural processes.
- Value diversity: differences in people's mental maps, worldviews or what they find 'worthwhile and desirable'
- Human behaviour: 'non-rational' behaviour, discrepancies between what people say they will do and what they actually do.
- Social, economic and cultural dynamics: the chaotic and unpredictable nature of societal processes.
- Technological surprise: unexpected consequences of, or unexpected developments in a technology.

[6] Ibid.; 3A: 7-8

Lack of knowledge:

- Inexactness: measurement errors; “we roughly know”.
- Lack of observations or measurements: lacking data that could have been collected, but hasn’t been yet; “we could have known”.
- Practically immeasurable: lacking data that in principle can be collected, but not in practice; “we know what we do not know”.
- Conflicting evidence: observations and/or measurements have been performed, but the resulting data allow room for competing interpretations; “we don’t know what we know”.
- Reducible ignorance: processes that we do not observe, nor theoretically imagine at this point in time, but probably in the future; “we don’t know what we do not know”.
- Indeterminacy: processes of which we understand the principles and laws, but which can never be fully predicted or determined; “we will never know”.
- Irreducible ignorance: processes that cannot (or not unambiguously) be determined by human capacities and capabilities; “we cannot know”.

The subcategories of lack of knowledge follow a continuum, where ‘inexactness’ is less fundamental, and ‘irreducible ignorance’ more fundamental. The first three degrees of ‘lack of knowledge have also been called unreliability, while the last four have been termed structural or systematic uncertainty[7].

In sum, uncertainty as defined by these sources is the entire set of beliefs or doubts that stems from our limited knowledge of the past and the present (especially lack of knowledge) and our inability to predict future events, outcomes and consequences (especially variability)[8].
The sources of uncertainty and their relationships can be summarised in the figure below:

[7] Ibid.; 3A: 9
[8] Ibid.; 3A: 9

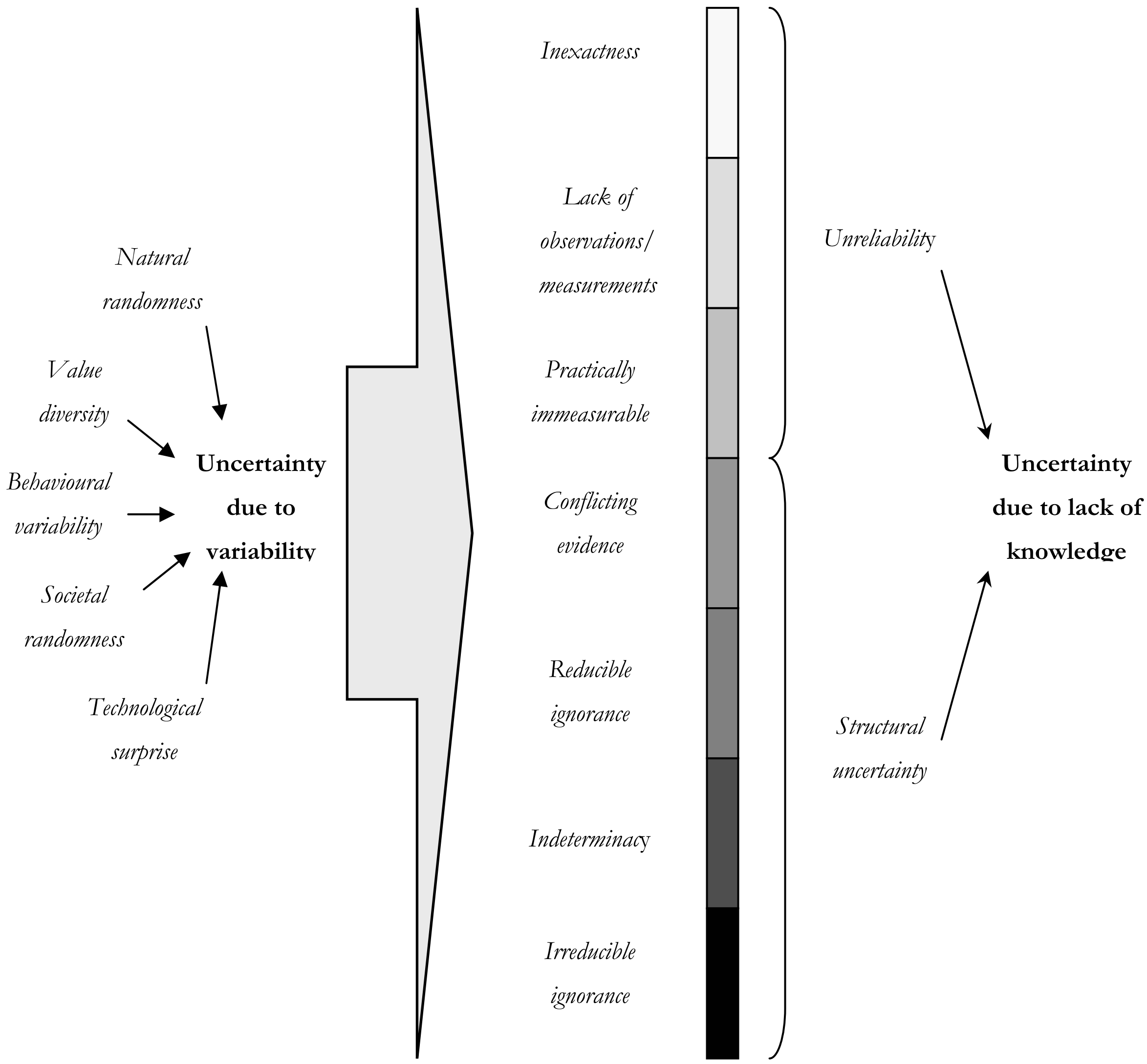

Figure: *Sources of Uncertainty*[9]

Uncertainty and risk

Uncertainty should not be confused with risk in this thesis. Risk has many definitions, but a general and often used one is 'all undesirable side-effects of modern technology'.

[9] Ibid.; 3A: 9

These two concepts can be viewed as "two sides of the same coin, *i.e.* the limited predictability of complex issues"[10]. However, in main parts of the work of van Asselt (2000), these two concepts are separated. The reason given for this is that these two issues have to be treated in a different manner: whereas uncertainty is a matter of our imperfect knowledge of the world and the underlying causes for this, risk is about how these uncertainties are *interpreted*.

This analysis is the first step of a novel approach to decision-support, the PRIMA approach[11]. In short, this method consists of identifying salient uncertainties as the first step, and risk analysis as the second. In this paper, I have concentrated on the first step.

Research perspective

In both the presentation of the debate, as well as in the analysis, I will try to take the methodological stance described in the 'strong programme' as presented by Bloor (1976)[12], especially the 'symmetry principle'. This principle refers to the treatment of different viewpoints without making *a priori* assumptions of what is right or wrong, rational or irrational, or which viewpoints that will win the day. This is not easy, as my limited selection of sources might lead to bias in one or another direction. However, I have tried to make this selection as broad as possible. Furthermore, not to take this stance would mean that I was to judge who is right and who is not. To do this would require me to look at the 'facts', as they were, which is not my task here.[13]

A consequence of using the symmetry principle is that the arguments aren't weighted against each other. This may give some of the arguments unrealistically high importance, in a social sense. Epistemologically speaking, however, this is less problematic, as it only brings to light views that might not otherwise be heard. This is not to say that all arguments are equally good: using the symmetry principle doesn't mean that everything should be taken at 'face value'. The rules of the scientific community still apply, in that claims have to be supported by empirical

[10] Ibid.; 4: 1
[11] Ibid.
[12] Bloor 1976; in Jasanoff, S. and B. Wynne 1998
[13] It can also be argued that because of inherent uncertainty, this is actually impossible.

research and logically sound reasoning. Therefore, claims can still be evaluated in terms of validity of the research.

Selection of sources

As the GM food debate has been around for some time, there is already quite a lot written on the subject. However, only one of the sources I found gives an extensive and updated overview of the debate. This is a report written by the Nuffield Council on Bioethics (1999)[14]. This limitation, besides the wish of being as updated as possible, made it necessary to use additional material from the news, the Internet, scientific journals and reports published by various institutions. A list of these sources will be given at the end of the bibliography.

These sources mostly come from the UK. This has three main reasons:

Firstly, the general public awareness about food issues is very high in the UK, spurred by the recent BSE crisis[15] and the Pusztai case[16]. Also, the Royal family has been involved in the debate (most notably, Prince Charles).

Secondly, most likely as a result of this, the GM food debate has been extensively covered in British news the last couple of years, probably more than in any other European country (perhaps with the exception of Germany). Moreover, several official research bodies have been involved in the debate.

Thirdly, a comparative study of several countries is beyond the scope of this thesis.

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[14] Nuffield Council on Bioethics 1999

[15] The "mad cow disease", Bovine Spongiform Encephalopathy (BSE), was shown to have a probable link to the deadly Creutzfeld-Jacob disease in humans, leading to the slaughtering down of tens of thousands of cattle in Britain. This also caused a major credibility problem for the British government that for a long time had ensured that there was no such link.

[16] This case is about the claims of a Scottish researcher, Arpad Pusztai, that his research showed detrimental effects on rats after eating GM potatoes. For a more comprehensive explanation, see chapter 3, 'Concerns about human health'.

Selection of arguments and presentation of the debate

The GM food debate involves a plethora of issues, making it impossible to give a full coverage within the limits of this paper. Therefore, I have limited myself to the most commonly referred to issues in the empirical material I have used. For the interested reader, I have briefly described additional issues I have encountered in appendix 2.

In these issues, I have concentrated on opposing views, leaving out statements or arguments that can be said to be in-between. This is both because such views are relatively rare, and because the focus of this thesis ultimately is on the underlying uncertainties. Also, by presenting the debate both in terms of pro and *con* arguments, such views are in many ways taken into account.

I have formulated the controversies as questions. This is because the underlying uncertainties can be seen as the reason for different arguments, given as answers to the questions. Moreover, the arguments in the debate often have a sense of certainty: GM food *is* unnatural; GM food *is* dangerous to the environment. By phrasing the controversies as questions, the uncertainties in them are highlighted.

Research questions

The following research questions have been used to achieve the aims as stated in chapter 1. As the writing of this thesis in many ways has consisted of exploratory work due to the novelty of the taxonomy used, these questions have necessarily been broadly formulated.

1. *What are the main controversial issues in the European debate on GM food?*

   This question will mainly be addressed in Chapter 3: this is a presentation of the GM food debate, as compiled from secondary literature, news, reports and Internet sites. Additionally, insights should be gained from the analysis in chapters 4 and 5.

2. *How are these controversial issues related to sources of uncertainty?*

   In the answer I give to this question, I will both analyse the controversial issues in terms of what makes them uncertain, as well as evaluate the taxonomy I'm using. The selected controversial issues are analysed in chapters 4 and 5, in terms of the two main sources of uncertainty: variability and lack of knowledge.

3. *What does such an analysis tell about the 'facts' in the debate?*

   This question will be a guide throughout the thesis.

Chapter 3: The Debate

As I mentioned in the last chapter, one of the means to achieve the aims of this thesis is to identify the main controversial issues in the GM food debate. This chapter consists of the collection of controversial issues I have identified to be most commonly referred to, and is organised in relation to major topics. The views described here are necessarily simplified; each of the main topics could potentially be a research project on its own. However, the goal of this presentation is to give the reader an idea of the scope and diversity of the debate, as well as an idea of what is argued on both sides in relation to specific issues.

1. Controversies in bioscience

I will start with controversial issues within the biological community, as large parts of the GM food debate evolve around disputes between biologists. These issues therefore can be seen to be of the more fundamental to the debate. I have restricted this section to two basic questions: what levels of analysis biologists use and how they view genetic engineering in relation to conventional breeding methods. Many more of the issues I have identified can be said to belong to this issue, particularly those concerning the environment and human health; For reasons of clarity, however, and because they often are treated separately in other literature, I have chosen to postpone the discussion of these more specific issues to later sections.

1.1 What is the right level of analysis?

A rough way of classifying research in biology is into microanalysis and macroanalysis. Microanalysis is the study of the cell and the inner functions (such as DNA-transcription and translation); researchers here are microbiologists, molecular biologists and bioengineers. One of the most common arguments that emanates from this level of analysis is that the changes that genomes undergo with genetic engineering actually is more well-characterised and controlled than with conventional methods[1]. Whereas conventional methods often is a trial-

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[1] Brill 1985; in Gottweis, H. 1998; OECD, 1993, Schell, 1994; in van Dommelen, A. 1999

and-error way of introducing useful traits into organisms, it is argued, genetic engineering makes it possible to take a well-characterised trait from one organism and transfer it to another. According to van Dommelen (1999), underlying this and similar arguments is an assumption that any addition or subtraction of genetic sequences will cause a fixed and comprehensible response at the level of the phenotype[2].

Researchers working on the macro-level, mostly ecologists and evolutionary biologists, often counter this assumption. They criticise what could be called an element of genetic determinism[3], stressing that the phenotype of an organism, especially its ecological traits and population dynamics, is not fully predictable from its genotype alone[4]. In the same vein, van Dommelen (1999) sites Lewontin (1992): "there is (…) only rudimentary knowledge of the causal pathways of development, so the forward mapping of genotypic description to phenotypic description is not possible except in special cases."[5] This is also why ecologists usually promote risk assessment on a case-by-case basis, evaluating each GMO [Genetically Modified Organism] in a field setting, instead of only evaluating the specific gene inserted[6].

Closely related to questions about the right level of analysis are competing models of biological complexity. Researchers working on the micro-level often use the so-called additive model, where the hazard potential of a GMO is the cumulative function of the respective hazard potentials of the host organism, the vector that is used to transfer the genetic sequence and the donor organism. By contrast, researchers working on the macro-level often use a contextualistic model, where fusing of foreign genetic material with an organism can have synergistic effects, that adds up to more than the sum of its parts[7]. While the additive model implies a quite straightforward and uncomplicated assessment of the effects of GMOs, the contextualistic model stresses the inherent complexity and unpredictability of nature.

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[2] van Dommelen, A. 1999
[3] Ho, M.-W. 1997; Gottweis, H. 1998; van Dommelen, A. 1999
[4] Colwell *et al.* 1985, Tiedje *et al.* 1989; in Gottweis, H. 1998; Millstone, E., E. Brunner et al. 1999
[5] van Dommelen, A. 1999; p. 101
[6] Colwell *et al.* 1985; in Gottweis, H. 1998
[7] van Dommelen, A. 1995; 1999

1.2 Is there a significant difference between GM crops and conventional crops?

Using these different models of complexity, researchers come to different conclusions of what genetic engineering means in the wider context of modern agriculture. On one side, there are those that argue that genetic engineering is only a more precise way of traditional breeding[8], and that the difference between the two practices is insignificant[9]. A typical statement is that humans have been altering plants and animals for centuries without causing serious problems[10]. The implication of this is that accepting the consequences of conventional plant breeding means that one should accept the consequences of genetically engineered plants. For instance, the president of the Deutsche Forschungsgemeinschaft stated that "concerns against release are directed against novel, non-natural risks of modern genetic engineering, and this argument can be refuted by the fact that the assumed risks are neither novel nor non-natural."[11]

On the other hand, there are those arguing that there is a significant difference. For instance, the Öko-Institut in Freiburg sees genetic engineering as capable of disturbing and renewing relationships in nature that essentially transcends what has been observed and achieved in natural processes until now. Furthermore, the institute characterises genetic engineering as an "injuring of contextual relationships" that has the potential of effecting unpredictable and irreversible ecological changes.[12]

Often, those who argue about the novelty and danger of GM crops use the analogy of exotic, introduced species that have become a nuisance or pest by lack of natural competitors[13]. By contrast, those who argue that there are no significant differences often use the analogy of domesticated species: these, they argue, are so specific for the controlled conditions of agriculture that they will not be able to survive in natural situations[14]. In the same vein, it is argued that "conventional introductions that cause problems are more likely to be radically

[8] *E.g.* Schell, 1994; in van Dommelen, A. 1999
[9] *E.g.* Young & Miller, 1987, van den Daele, 1992; 1994; in van Dommelen, A. 1999
[10] Brill 1985; in Gottweis, H. 1998
[11] Markl, *Die Zeit* 8/9 1989; in Gottweis, H. 1998; p. 248
[12] Kollek 1992; in van Dommelen, A. 1999; p. 102. Similar views are expressed by, amongst others, van Dommelen 1999.
[13] van Dommelen 1995; 1999. Some examples are mussels that have clogged up Canada's lakes, the rabbits in Australia and the grey squirrels that threaten the native red squirrels in the UK.
[14] van Dommelen 1995; 1999.

different from anything present in that environment before", stressing that "in the case of GM plants, a familiar crop with few, often very few, genetic changes is involved."[15]

The comparison of genetically modified and conventional crops is one of the most common issues in the debate. It can also be seen to be one of the most fundamental: defining GM crops as not being 'significantly different' from conventional crops implies that accepting the consequences of one type of crop is extended to the other.

As will become clear in the remains of this chapter, the 'normalisation' of GM crops is used in several other contexts, as a general counter-argument to those opposing such crops. Therefore, several of the issues described in the following can partially be seen as arguments concerning this particular controversy.

2. Environmental arguments

Technological developments in the last century have in many ways increased our living standard. However, in several cases, these developments have led to damage to the environment. In addition, occasional disasters, such as Chernobyl and Seveso, have made people sceptical of scientists and politicians that reassure that these developments are completely safe[16]. Therefore, it should come as no surprise that also GM crops are included among the developments that cause concern.

In the following, I will describe the most common of these concerns.

2.1 Do the field studies already conducted prove that GM crops are safe to the environment?

On the most general level, there are disputes about the field studies that already have been conducted. According to the Nuffield Council on Bioethics (1999), during the period from 1986 to 1997, approximately 25.000 transgenic crop field trials were conducted on more than

[15] Nuffield Council on Bioethics 1999; p. 98
[16] Kemp, P. 1996

60 crops with 10 traits in 45 countries, without any adverse effects found that aren't also common in conventional agriculture[17]. This is often used to contradict arguments that GM crops are dangerous to the environment. However, to others, these studies are nothing more than 'field containments'[18], and are done over too short time to tell anything about what will happen when the crops are planted in a normal agricultural setting[19]. Another issue is the rules that are imposed on the farmers conducting the experiments. Some feel that these are "bound to be broken in the practical farming situation"[20], and that this isn't taken into the evaluation of the farm trials[21].

2.2 Will GM crops reduce or increase the amount of herbicides and/or pesticides used?

The most common GM crops are herbicide- or pest-resistant crops[22]: virtually all the arguments that can be classified as 'environmental' deal with these two types of GM plants. The most direct issue is whether they reduce or increase the use of herbicides and pesticides. The use of these chemicals has widely been acknowledged to be detrimental to the environment since Rachel Carson published her book "Silent Spring" (1962). Therefore, the question of whether GM crops reduce or increase their use is an important one[23].

From what I have found, the answer to this question is reduction when current GM crops are evaluated. For instance, a commentary in *Nature* claims that "expression of the *Bt* protein into cotton has reduced the application of specific, highly toxic pesticides by more than 80%."[24] However, it has been argued that pest-resistant plants also could kill beneficial insects that

[17] Nuffield Council on Bioethics 1999; p. 29
[18] OECD 1993
[19] Mayer, S. 1999; Wynne, B. 1999
[20] Mayer, S. 1999
[21] Mayer, S. 1999; Wynne, B. 1999
[22] See appendix 1.
[23] It has been argued that solutions provided by genetic engineering techniques do nothing to alter the fundamental problems of intensive farming (van den Daele, W. 1995; p. 75), and that instead, one should focus on alternative methods, such as organic farming. However, I won't treat this issue here (although I will have a short, related discussion under Third World arguments), as it would require additional discussions of both conventional crops and organic farming. As my focus is on GM crops, I perceive this to be on the side of my subject.
[24] Trewavas, A. 1999

feed on the pests[25]. Another concern is that these plants might lead to a more efficient selection for pests or weeds that can survive current attacks. Realisation of either of these concerns would lead either to increased use of pesticides or a continually higher demand for new pesticides. For instance, the *Union of Concerned Scientists*[26] has stated that "because the *Bt* toxin is produced in the tissues of the plants, it is protected from the environment and does not break down. Under these conditions, pests feeding on the crops are exposed to high levels of toxin continuously over the life cycle of the crops. No better recipe could be found for eliciting resistance [of insects to the *Bt* toxin]. In fact, it is now widely agreed that in time the use of *Bt*-containing crops will lead to the development of resistant populations of pests."[27]

In a similar way, it is argued that herbicide-resistant plants might lead to the selection for 'super-weeds'. However, here the debate seems to be more focused on the possibility that the genes for herbicide-resistance themselves can be transferred to weeds, which is the topic of the next section.

2.3 Do genes transfer from GM crops to weeds?

If the genes coding for herbicide-resistance were transferred to other plants, the consequence could be that weeds got the same resistance to herbicides as the GM crops. On one side, it can be argued that this represents a small possibility, with reference to small registered amounts of gene-transfer from conventional crops. What's more, according to conventional biological theories, the weeds would have to be related to the crop plants for hybridisation (and thereby gene-transfer) to occur[28]. However, Kareiva and Parker (1994) point out that whereas conventional plant breeding often is based on favourable polygenic traits (requiring the interaction of several genes), genetic engineering is often based on single-gene traits. Furthermore, spread of favourable genes is "much more likely and rapid for a simple dominant gene than for a complex polygenic trait."[29]

[25] Nuffield Council on Bioethics 1999; p. 102
[26] UCS 1995; in van Dommelen, A. 1999
[27] Ibid.; p. 25
[28] An example of this is the weed wild mustard (*Brassica campestris*) and the crop plant canola (*Brassica napus*)
[29] Kareiva & Parker 1994; in van Dommelen, A. 1999; p. 91

Arguments regarding this kind of gene transfer are often met with reassurances that today's safety-measures are good enough. For instance, a commentary in Nature argued that "pollination distances beyond which growing siblings are not produced were painstakingly measured by ecologists 20 years ago and, as a result, a separation distance of about 50 metres is used internationally to maintain separate lines of the same crop at greater than 99.5% purity."[30] However, other research shows different conclusions. For instance, the Nuffield Council on Bioethics (1999) refers to recent work with oilseed rape from the Scottish Crop Research Institute in Dundee. Here, the scientists "found that, although the density of pollen decreased rapidly with distance from the source, (…) pollination occurred up to four kilometres from the test sites, (…) probably carried by bees. They concluded that 'farm to farm spread of OSR (oilseed rape) transgene[31] will be widespread'."[32] Also, the recent GM seed scandal in Europe has been used to make a point in this direction: Here, pollen from one of the seed producer's GM crops had been carried by unusually strong winds and fertilised some of the plants in a neighbouring non-GM crop. This resulted in inadvertent planting of crops containing GM seed around Europe.

Apart from the question whether or not gene spread will happen, some feel that this anyhow is acceptable, as herbicide-resistant genes are widespread in nature already. A possible spread would then be comparable to existing natural processes.[33]

2.4 Do GM crops have adverse effects on wildlife?

Apart from the problems of resistant pests and weeds, there have also been concerns raised that GM crops can have adverse effects on surrounding wildlife. In May 1999, a group of researchers at Cornell University published a report in *Nature* that has been used by many as a back up of this argument. Their research showed that larvae of the monarch butterfly that had been reared on milkweed leaves dusted with pollen from *Bt* corn "ate less, grew more slowly

[30] Trewavas, A. 1999
[31] See appendix 1.
[32] Nuffield Council on Bioethics 1999; p. 101
[33] von Schomberg, R. 1998

and suffered higher mortality than larvae reared on leaves dusted with untransformed corn pollen or on leaves without pollen."[34]

These results could mean that the numerous fields with *Bt* corn in the USA could threaten the monarch butterfly, a popular species known for its migratory behaviour. But criticism has been expressed on various grounds. For instance, a commentary in *Nature* described the study as "exaggerated out of all proportions by the media, whereas more realistic assessments [were] ignored."[35] One of the alternative assessments the commentary refers to indicates that "the behaviour of non-target insects can also play a part in determining how their populations will be affected by *Bt* plants."[36]

Furthermore, the fact that the Cornell study was carried out only in the laboratory resulted in suspicion of generalisability of the results to the real world[37]. A recent study, reported by the BBC News, was conducted both in the laboratory and the fields, and showed that *Bt* corn had no effect on black swallowtails, another common butterfly-species in the USA. Although, according to BBC News, the swallowtail is considered to be less sensitive to the toxin than the monarch, "the swallowtail is much more likely to be exposed to the pollen."[38]

Another way in which GM plants could have adverse effects on wildlife is through spreading into the surroundings and thereby replacing naturally occurring species. To do this, GM plants would have to have a selective advantage in the wild, which by no means is a resolved issue. For instance, the Nuffield Council on Bioethics (1999) states that "it is not generally realised that crop plants are usually uncompetitive outside their normal agricultural environments, since they have been bred for characteristics that humans want, at the expense of traits that enable them to flourish in wild conditions."[39] However, they also cite a research report that suggests that GM insect-resistant rapeseed survives better in a wild environment than non-GM oilseed rape, "so caution is required and further research is vital."[40]

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[34] Losey, J. E., L. S. Raynor et al. 1999
[35] Trewavas, A. 1999
[36] Schuler, T. H., R. P. J. Potting et al. 1999
[37] *E.g.* Crawley, M. J. 1999
[38] BBC News 6/6 - 2000a
[39] Nuffield Council on Bioethics 1999; p.98
[40] Ibid.; p. 99

3. Concerns about human health

Demands for further research has also been expressed in relation to the next case:

3.1 Does Pusztai's research indicate that GM food is dangerous to human health?

In 1998, a researcher working for the Rowett Institute in Scotland, Dr. Arpad Pusztai announced that his research showed stunted growth and reduced immune responsiveness in laboratory rats that had been fed genetically modified potatoes[41]. He has later reduced his claims of damage to the rats' digestive systems, but has added that some of the damages seemed to be due to the specific process of modification itself, and not because of the specific gene that was inserted (coding for a lectin)[42].

Shortly after the annunciation, Pusztai was suspended because of what the board at the Rowett Institute perceived to be an unscientific way of handling research. This case stirred up what by some has been characterised as a 'feeding frenzy' in British newspapers, where terms like 'Frankenfoods' appeared for the first time. In addition, 20 seemingly renowned researchers from all over the world quickly gave their support to Pusztai.

However, a resulting investigation of the findings by the Royal Society concluded that "the reported work from the Rowett is flawed in many aspects of design, execution and analysis and that no conclusions should be drawn from it" and they furthermore "found no convincing evidence of adverse effects"[43]. Furthermore, there seems to be few people, at least in the scientific community, arguing that this case can be counted as 'evidence' - only that there are indications that more research should be done.[44]

Whatever the truth, many have used this research as a general indication that GM food may be dangerous to human health. Countering this indication is the argument that the testing of GM

[41] Granada Television, "World in Action", 9/8 – 1999.
[42] Ewen, S. W. B. and A. Pusztai 1999
[43] The Royal Society 1999
[44] For instance, one of the researchers that came to the support of Pusztai have stated that the reason for doing so had to do with the unfair treatment of Pusztai by the Rowett Institute, and the odd circumstances surrounding the case. Furthermore, he claims that Pusztai's message was simply that GM foods require careful testing, not that all GM foods were unsafe (Rhodes, J. M. 1999).

food is already more rigorous than the evaluation of conventional counterparts[45], and that none of the earlier experiments have shown negative side effects.

Apart from this study, concerns have been raised on several, more specific grounds.

3.2 Can eating GM food lead to an altering of your DNA?

One of them is whether DNA from GM food can transfer across the wall of the abdomen to the host and lead to genetic alteration of that host. This concern is generally considered to be unrealistic, and is often met with arguments like "we eat large amounts of degraded and undegraded DNA in our everyday diet" and "DNA consumed in the diet is very unlikely to survive intact beyond the stomach and into the gastrointestinal tract. DNA that remains after digestion consists of very small fragments which do not contain whole genes."[46]

3.3 Do the marker genes in GM food lead to a higher incidence of antibiotic-resistant gut bacteria?

A related problem that seems to have more merit in the scientific community is that genes coding for antibiotic-resistance can transfer from GM food to bacteria in the digestive system. An increasingly common problem in hospitals is disease-causing bacteria that have become resistant to treatments with multiple varieties of antibiotics. These are thought to have evolved through the transfer of genes[47], coding for antibiotic resistance, between different bacteria. This problem is especially common in an environment where antibiotics are used extensively, as this gives a selective pressure on the bacteria to evolve resistance. In addition to hospitals, such an environment is the modern animal farm, where antibiotics often are added to animal feed[48].

[45] Gasson, M. J. 1999
[46] Nuffield Council on Bioethics 1999; pp. 32-33
[47] This process is called lateral gene transfer, which is common in bacteria, and is one of the major means of bacterial evolution (Ochman, H., J. G. Lawrence et al. 2000)
[48] The reason for this is both to prevent disease, as well as to use the feed more efficiently, as the antibiotics kills a large portion of the gut bacteria that usually use up some of the energy in the feed.

In the case of GM food, the concern is about the marker-genes that confer resistance to antibiotics[49], which may get transferred to bacteria in the gut of the host. An ongoing, illustrative case involves approval by the EC of a GM maize variety produced by Ciba-Geigy (now Novartis), projected for animal feed. The UK Advisory Committee for Novel Foods and Processes (ACNFP) recommended against authorisation on the grounds that the antibiotic-resistance marker gene might get transferred to bacteria in the gut of the animals given the feed. This could eventually present a risk to humans in contact with the animals[50]. But, as the Nuffield Council on Bioethics (1999) claims, the widespread use of antibiotics in animal feed and for clinical use probably represents a much larger problem. Then the discussion becomes whether transferred antibiotic-resistance from GM food is considered an unacceptably large addition to this more general problem, or not[51].

Another thing is that the second generation of GM products are expected to be made without the use of these types of marker genes. This would mean that the controversy on this particular issue could be solved in the future.

3.4 Will GM food have higher amounts of allergens?

Another form of gene transfer that has raised concern involves allergens[52]. The concern is that the allergens in one plant could be transferred to another during the process of modification, making it difficult for allergic people to avoid them. According to the Nuffield Council on Bioethics (1999), there is also a documented case where such transfer has happened. This involved transfer of a gene from the Brazil nut to soybean, where the modified soybean was shown to give the same allergic reactions as the nut in seven out of nine individuals[53]. On the other hand, the Council remarks that the work with the soybean was discontinued, and that the product never was released. This illustrates the point they make, that testing for allergens is a routine part of safety assessment procedures, making such transfer unlikely to go unnoticed before the product reaches the market.

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49 See appendix 1.
50 Nuffield Council on Bioethics 1999; p. 32
51 Ibid.
52 Allergens are various substances that may cause allergic reactions.
53 Nordlee *et al.* 1996; in Nuffield Council on Bioethics 1999; p. 33

However, as the Nuffield Council remarks, the generation of new allergens can never be excluded, and that this has to be a focal point for future safety assessments[54].

3.5 Can genetic modification lead to the conversion of non-pathogens into pathogens?

The same problem has been pointed out in relation to pathogens. A pathogen is a micro-organism that causes disease in another organism by direct interaction (*i.e.* infection)[55]. In the case of GM food, the concern is if genetic modification can lead to an inadvertent conversion of a non-pathogen into a pathogen by changing or adding (or, in rare cases, removing) some trait. According to the National Academy of Sciences (1987), the possibility that this will happen is "quite remote", given the "impressive array of requirements for pathogenicity"[56].

However, according to van Dommelen (1999), this statement assumes that non-pathogens do not possess *any* of the required traits for pathogenicity. This assumption he calls "entirely unfounded", on the grounds that a non-pathogen might miss only one of the required traits, which easily could be (unintendedly) introduced by artificial modification[57]. Also, the fact that many of the micro-organisms used as vectors in genetic engineering originally are pathogens may be a reason that this concern is raised.

4. Third World arguments

In this section, I have placed the arguments that relate to the implementation of modern agricultural biotechnology in Third World countries. A common aspect of these arguments is that they are about the future: virtually all of the world's production of GM crops today is in developed countries, with the small exception of China, having 1% of the world's total area of transgenic crops[58]. Although environmental and human health issues also are regarded as important in relation to the Third World (with the additional problem that safety standards

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[54] Nuffield Council on Bioethics 1999; p. 33
[55] van Dommelen, A. 1999
[56] NAS 1987; in. van Dommelen, A. 1999; p. 73
[57] van Dommelen, A. 1999; p. 76
[58] James, C. 1999

often are set lower in this part of the world), the focus in the debate is on socio-economic effects[59]. Therefore, I have restricted the description here to this last topic.

Often, analogies have been made between the 'green revolution'[60] and the 'genetic revolution': those against generally focus on the negative social effects of the green revolution[61], while those for generally focus on the increased world food production it has led to[62]. These are also the main issues in this section.

One of the most common, positive arguments in the GM food debate is that GM crops have the potential to solve the hunger problem. Embedded in this argument are two assumptions that are hotly debated: GM crops give increased yields compared to traditional crops, and increased yields are necessary to solve the hunger problem. I will treat each of these assumptions in turn.

4.1 Can genetic engineering increase crop yields?

To back up this argument, proponents often cite research on new GM crop varieties that are developed specifically for the conditions in some Third World countries. For instance, the Nuffield Council on Bioethics (1999) mentions a GM rice variety that has genes from two wild rice relatives inserted into the best performing Chinese rice hybrids, and which has risen yields by 20-40%. Furthermore, they argue that genetic engineering may be better suited than conventional breeding to tackle some of the most serious problems for farmers in Third World countries, such as temperature, moisture and biotic stresses (*e.g.* viruses, fungi, insects and weeds)[63].

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59 Campagna, N. 1995
60 This term is used on the major implementation of modern agricultural methods in developing countries that started in the 1960's.
61 For instance, according to Campagna (1995), the green revolution "led to a pauperization of hundreds of thousands of small farmers who could not afford the techniques (…). Thus, many small farmers had no other choice but to work for rich agricultural enterprises, sometimes under conditions that were not very different from slavery." (Campagna, N. 1995; p. 212).
62 *E.g.* Trewavas, A. 1999
63 Nuffield Council on Bioethics 1999; pp. 65-66

On the other hand, the superior yields of today's commercial GM crop varieties seem to be a disputed claim. For instance, the ESRC (Economic and Social Research Council) (1999) states that there is "a lack of conclusive data about GM crop yields". This is grounded on that "several recent official US studies have pointed to variability of yields across different crops and regions."[64]

Moreover, there are those arguing that growth in yields can still be achieved with conventional (modern) farming techniques, and that this growth is large enough. Illustrative of this is the conclusion given by Dyson (1999): "Of course, there will be new crops and improved seeds. But most of the required increase in the world's harvest will come from the application of procedures and knowledge that we already have to the current world harvested area."[65]

On a more fundamental level is the argument that monocultural, large-scale farming (which GM crops are a part of) as a whole is *less* productive than small, diverse farms. One of the most notable proponents of this view is Vandana Shiva, director of the Research Foundation for Science, Technology and Natural Resource Policy, and otherwise a well-known ecofeminist. She claims that most current measures of yields are only partial, in that they take into account only one plant-variety. However, according to Shiva, on a polycultural farm there are many plant-varieties that are considered useful as food in developing countries. When these varieties are taken into account, the yields actually turn out to be much higher on a small, polycultural farm[66].[67]

4.2 Are increased crop yields necessary to solve the hunger problem?

The view expressed by Shiva (1999) is related to the second assumption mentioned above: that increased crop yields are necessary to solve the hunger problem. To give this argument merit, many point to the fact that the world's population is growing at an increasingly rapid

[64] ESRC Global Environmental Change Programme 1999; p. 11
[65] Dyson, T. 1999
[66] Up to five times higher, according to an article published on the homepage of the Third World Network (Third World Network 2000).
[67] Based on notes from a lecture by Shiva at the conference "Genmat i et Nord-Sør Perspektiv" in Oslo, September 1999.

rate. Considering today's low expansion rate of arable land, this means that the amount of cultivated land supporting food production will decrease per person in the years to come[68].

On the other hand, there are those arguing that there is already more than enough food in the world today. For instance, Oxfam GB (1999) states that "there is no crisis in world food production on the horizon" and furthermore, that "hunger will only be eliminated if governments and international organisations such as the World Trade Organisation implement substantial policy changes in favour of resource redistribution, poverty reduction, and food security."[69]

This seems to be a very common stance: redistribution and poverty are the real problems, not a physical shortage of food in the world. However, it is also argued that attacking these problems meets severe hindrances because of political difficulties of redistribution, both within and between countries, as well as logistical problems and costs of food distribution. Then, GM crops may represent an alternative route, which is easier to handle.

4.3 Will implementation of rDNA technology lead to the exploitation of poorer countries?

Apart from the hunger problem, there is also a lot of debate on socio-economic effects. Of the more serious issues is the question whether GM technology will lead to a downright exploitation of poorer countries. Typical of the affirmative view on this is the stance of Oxfam GB (1999): "GM crops and related technologies are likely to consolidate control over agriculture by large producers and agro-industrial companies, to the detriment of smaller farmers"[70]. A much-cited case used as an example of this is the so-called 'terminator'-technology (originally 'Technology Protection System' (TPS)), a specific instance of gene use restriction technologies (GURTs). Basically, it consists of introducing a gene into a plant that makes the plant unable to produce viable seed. If this technology is implemented, this means

[68] Nuffield Council on Bioethics 1999; p. 59
[69] Oxfam 1999; 'Summary'
[70] Ibid.

that the farmer has to buy new seed from the seed producer every year, instead of using the seeds from last year's crops.[71]

However, that this will worsen the situation is often met with arguments about the similarity with the current state of affairs: Farmers already have to buy new seeds every year for plant varieties that are F1-hybrids[72], such as maize. In a similar vein, the Nuffield Council on Bioethics (1999) states that "GURT technology is only the latest in a long line of more or less efficient ways of compelling farmers to buy seeds from the companies that have developed them, which is thought perfectly reasonable for most researched products."[73]

Another issue is the problem of 'biopiracy': "the unauthorised and/or uncompensated gathering, for commercial advantage, of developing-country and international biological resources"[74]. The biological resources in question are usually plant varieties that have been domesticated for generations by local, often indigenous farmers. By patenting such plant varieties, companies are seen to gain profits on the knowledge developed by these farmers, without giving anything in return. In addition, there is a fear that such activities will restrict the use of the patented varieties to those that can afford them, which would amount to something comparable to theft. On the other hand, the current patenting system doesn't allow for patenting of genes or plants *per se:* the patent must involve an innovative step, such as a transgene construct with the gene, or a new production procedure.

4.4 Will poorer countries be excluded from the benefits of rDNA technology?

In addition to arguments that relate to the implementation or use of gene technology in Third World countries, there are also those who are concerned that poor countries won't be part of the development at all, and that, as a consequence, the gap between rich and poor will grow.

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[71] In October 1999, the most profiled proponents of this technology, Monsanto, announced that they were not going to commercialise technology that made plants sterile (Shapiro, R. B. 1999). However, other versions of GURTs are still researched and 'terminator' still figures in the debate.
[72] F1-hybrids are a non-GM mixture of two different parental strains, each with quite unfavourable characteristics on their own. It is the concert of the traits in the offspring that gives them their superior traits, and planting the seed from these will only lead to an unwanted mixture of the parental strains and the wanted, hybrid strain.
[73] Nuffield Council on Bioethics 1999; p. 77

One of the arguments for this is that little of the R&D on GM crops is thought to be suited for developing countries. According to the Nuffield Council on Bioethics (1999) "a very small and dwindling proportion of research money and GM expertise is in public-sector systems, both international (CGIAR) and national (Brazil, China, India, Mexico and South Africa), which are relevant for developing countries."[75] Furthermore, the focus of private-sector systems is on "requirements of labour-saving production by large farms for developed markets"[76], such as advances directed at crop quality or management, while what developing countries need is employment-intensive production of food staples and higher yields.

Another concern is the possibility that exported vegetal substances that are a major part of many Third World countries' economies may instead be produced by GMOs (such as bacteria) in the industrialised countries, making import unnecessary or economically unfeasible.[77]

5. Ethical and/or religious arguments

The last section of this chapter deals with the arguments that are based on people's religious or ethical beliefs and views. Ethics can be understood as the fundamental view of what is the right way to live[78], and extends into all areas of life. The same can probably be said about religion, although a straightforward definition here seems impossible[79]. In this way, there are many issues that potentially can belong to this section, which also is illustrated by the treatment of almost all of the above issues (except controversies within bioscience) as ethical in the already mentioned report by the Nuffield Council on Bioethics (1999). However, for practical reasons, I have chosen to restrict this section to arguments that can be understood purely in terms of ethics or religion, and that doesn't fit under any of the other themes.

[74] Ibid.; p. 71
[75] Ibid.; p. 68
[76] Ibid.; p. 60
[77] Campagna, N. 1995; pp. 211-212
[78] Kemp, P. 1996; p. 36
[79] Kuper, A. and J. Kuper 1989; p. 698

5.1 Is GM food 'unnatural'?

Genetic engineering makes it possible to breach the 'species barrier', something that would never happen in nature or in conventional breeding: it is not possible to mix traits from species that are far apart on the evolutionary tree with ordinary cross-breeding. This step is by some people considered as a step too far, even though the same people can be prepared to accept that we already live with considerable human intervention in the environment.[80] Some of the people who argue this, do so from a religious perspective. For instance, Prince Charles feels that genetic engineering takes humans into the realms that belong to "God and God alone"[81]. However, the Nuffield Council on Bioethics (1999) also stresses that there is a deep-rooted belief that we 'tinker' with nature at our peril, despite the decline of formal religion[82]. The much used term 'Frankenfood' tells a lot about this belief, where Mary Shelley's story is used as an analogy to show that 'tampering' with nature can only bring disaster.

The claim that GM food is unnatural can, furthermore, be viewed as having the implicit assumption that the environment has rights on its own, including the right not to have species boundaries violated[83].

5.2 Does rDNA technology lead to a further mechanisation of nature, and is this bad?

Closely related to the claim that GM food is unnatural (and maybe one of the reasons for this claim) is the argument that genetic engineering leads to a (further) mechanisation of nature. The 'factory farm' is a metaphor that often shows up in discussions of modern agriculture[84]. To some, genetic engineering is a further attempt to control nature in this manner. For instance, Deutcher Naturschutzring stated in 1989 that: "Genetic engineering is one of the technologies which reduces life, in the tradition of the mechanistic world model, to a material and controllable principle; the domination of nature and technological utility are already anticipated by this methodological approach."[85] In a similar vein, Prince Charles asks the

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[80] Nuffield Council on Bioethics 1999; p. 96
[81] BBC News 6/6 - 2000b
[82] Nuffield Council on Bioethics 1999; p. 7
[83] Ibid.; p. 96
[84] *E.g.*, Gottweis, H. 1998; p. 1
[85] Cf. Gottweis, H. 1998; p. 251

question: “Are we going to allow the industrialisation of Life itself, redesigning the natural world for the sake of convenience and embarking on an Orwellian future?”[86]

Illustrative of the divergent views on this subject, Kemp (1996) tells a story from a 1986 conference on bioethics in Dubrovnik: “At the beginning of the meeting, there were some that insisted that ethics only applied to humans,” being “convinced that humans are cultural beings that have to breach with nature, conquer it and control it to create a good and safe society. Therefore, humans should have the right to treat everything in nature as material for the development of their own material welfare.” However, according to Kemp, this attitude changed somewhat after the presentation of a hypothetical, extreme case: pigs genetically modified to have no eyes, on the grounds that these pigs would be more interested in food and, as a consequence, grow faster. Apparently, no one was willing to defend this, although there was no reason to suspect that the pigs would be in pain or frustrated. The reason, Kemp asserts, was that the pigs on beforehand would have been deprived of the possibility of sight, and thus treated as “pure material to manipulate”.[87]

Extending the views of the participants who felt that humans should have the right to manipulate nature, there are also those who claim that to do so is an outright duty. Many religious people perceive the ‘cultivation and reordering of nature’ as a duty laid on humanity by God, and the neglection of the materials placed before us as an ingratitude for God’s bounty[88]. The duty to manipulate nature can also be argued on an ethical level, if one perceives a potential for improving the human condition. For instance, the Nuffield Council on Bioethics (1999) argues that “GM crops are expected to produce more food, or more employment for those who need it most urgently.” Therefore, “introduction of GM crops on a large scale [is] a moral imperative.”[89]

[86] BBC News 1/6 - 1999
[87] Kemp, P. 1996; pp. 186-187, free translation
[88] Nuffield Council on Bioethics 1999; pp. 14-15
[89] Ibid.; p. 58

From this chapter, it should be apparent that the characterisation of the GM food issue as a complex one is accurate[90]. The next two chapters will be an attempt to describe some of this complexity, in terms of what the underlying uncertainties are.

[90] See chapter 1.

Chapter 4: Variability

This and the next chapter is the analysis of the debate in terms of sources of uncertainty (the second research question of this thesis). Here I will explain my interpretation of each of the sources of uncertainty before identifying relevant arguments. This chronology is not descriptive of the actual work, which has been more like a two-way street: during the analysis, I have added definitions to the taxonomy. This is because the taxonomy as depicted in van Asselt (2000) is rather general and on a theoretical level. Applying the taxonomy to the real world thus demands some additional considerations, as often is the case when theory is put into practice.

A point to be stressed is that the sources are not mutually exclusive. The reason for this is threefold:

Firstly, as mentioned in chapter 2, variability can in many cases be seen as a source of lack of knowledge. This means that several controversial issues need to be analysed in terms of both.

Secondly, most of the controversial issues have a multiple set of (relevant) arguments, and these often come from different definitions of the problem, for which different sources may be relevant. Furthermore, using the 'symmetry principle' means that these different definitions should all be taken into account.

Thirdly, the analysis itself involves uncertainty: it is in several cases impossible to classify a particular controversial issue to a particular source of uncertainty without implying an artificial certainty about the issues.

For a summary of where I have placed the different controversies, the reader is referred to table 1 at the end of chapter 5.

In the following, I have treated each of the subcategories of variability as listed in chapter 2.

I.i) Inherent randomness of nature

Inherent randomness of nature has also been called natural randomness and (unobserved) seasonalities[1]. This source of uncertainty is about natural processes that are beyond the control of human intervention (but that still can be influenced by such), and that are difficult or impossible to predict. This will eventually create uncertainty in conclusions drawn about issues that involve such natural processes.

Of the controversial issues I have described, the ones that have to do with interactions with ecosystems seem to fit well under this source. Ecosystems are intricate and open systems, which means that they potentially are influenced by both local and global factors: these can be particular soil-conditions and compositions, the particularities of the surrounding fauna and wildlife (such as the bees in the case of gene transfer), and weather conditions (such as strong winds, in the same case as above), which in the last instance will be influenced by the global climate. Because of this, ecosystems are often viewed as complex[2], where uncertainty will always be the case, no matter how much knowledge is gathered about them[3]. Furthermore, all of the processes in an ecosystem can be called 'natural'. This means that the controversial issues classified as 'environmental arguments' (2.1 – 2.4) can be seen as partly coming from this source of uncertainty, as they involve uncertainties regarding how the GM crops will interact with the ecosystems they are placed in.

Another case that is relevant to this source is the question regarding increased antibiotic-resistance (3.3): here the random nature of bacterial evolution plays a part[4], in form of uptake of marker genes in the digestive system.

Additionally, two of the concerns about human health could be included here: the increase of allergens (3.4) and the conversion of non-pathogens into pathogens (3.5). Both of these controversies are partly about the possibility that the transgenes could be inserted in or nearby other genes and thereby affect them in some way. Furthermore, the effects a transgene on a

[1] van Asselt, M. B. A. 2000; 3A: 8
[2] *E.g.,* Dale, V. H., S. Brown et al. 1999
[3] See chapter 1.

foreign genome can, as is the case with effects on the ecosystem, be viewed as being a complex problem: there are a number of variables to take into consideration, and these aren't necessarily well-defined and easy to determine[5]. However, I perceive this issue to be more about the randomness of the technology (I.v), than of natural randomness: Targeting the insertion of a transgene in a chromosome is currently impossible, making the insertion itself random. Also, a genome is more isolated and less dynamic than an ecosystem, making the 'natural randomness' in a genome of a lesser degree than in an ecosystem.

I.ii) Value diversity

Value diversity has also been called cognitive variety, subjective judgement and disagreement, and moral uncertainty[6]. A general definition of values is "standards or qualities that are considered worthwhile and desirable"[7]. Such values aren't necessarily 'subjective'. For instance, there are general values, such as 'thou shalt not kill' that can be considered as objective, in that they are agreed upon by most people[8]. Similarly, many values can be considered as objective within a culture, a society, a community, or even within a group. The problem is when two or more groups that have different, internally 'objective' values evaluate the same issue: The differing views creates an uncertainty in *generalisations* about what is 'worthwhile and desirable', or, to phrase it differently, when the evaluation is done on a higher level of abstraction.

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4 The characterisation of evolution as random is in itself a contested claim. However, because this is outside the scope of this thesis, I will leave it as is.

5 The expression of genes depends on many factors, such as neighbouring regulatory DNA sequences (so-called promoter and inhibitor regions), the proteins and RNA-molecules that attach to these regions (which are coded for by other genes, which in turn also have regulatory sequences) and where the gene is placed in a genome (for instance, genes placed at or near the tip of chromosomes are rarely expressed at all). In addition, multiple genes often work together in intricate ways to produce a particular product. Although genome sequencing (such as in the Human Genome Project) has become much easier with the development of bio-informatics, identifying all the base-pairs in a genome doesn't mean that all the functions genes might have in the genome, or even all of the genes, are identified. The case is further complicated by our limited knowledge of the gene-products that have been identified. For instance, hormones (one class of gene-products) have very diverse functions in the body, and the experimental use of these in medicine often seems to be a hit-or-miss endeavour. (Cf. Griffiths, A. J. F., J. H. Miller et al. 1996)

6 van Asselt, M. B. A. 2000; 3A: 8

7 Encarta Encyclopaedia 2000

8 See, for instance, Tiles, M. and H. Oberdiek 1995

The most obvious controversies to be placed under this source are the ones classified as ethical and/or religious (5.1 and 5.2). Ethics and religion are the source of many human values, which can be discussed, but on a level that is beyond the debate on empirical evidence. For instance, Kemp (1996) states that ethics in and by itself cannot be a science, and that the foundation for ethics should be in the *story*[9]. Whether GM food is perceived to be 'unnatural' or thought to lead to a mechanisation of nature that is a 'reduction of life', depends, amongst others, on definitions of what is natural, mechanisation, life, God, the relationships between them, and the relationships between them and ourselves. Such definitions cannot be rationalised, quantified or empirically assessed. For instance, when discussing views on 'unnaturalness', the Nuffield Council on Bioethics (1999) describes them as having "something of an 'unarguable' quality, inasmuch as no amount of information, explanation or rationalisation would move a person with such views from their position."[10] Following this view means that, in these cases, 'value diversity' can be seen as the only source of the controversy.

Perhaps on a less fundamental level is the value diversity in the question regarding the possible exploitation of poorer countries (4.4). Exploitation is a value-laden expression, and implies that somebody is using their power in a selfishly or unfair way for the sake of own advantage or profit[11]. The coining of corporate control or corporate activities such as the implementation of 'terminator' or 'biopiracy' (which both are value-laden words!) as 'exploitative' thus depends on if these activities are perceived to be unfair. For instance, the Nuffield Council's remark about the 'terminator' technology, that compelling farmers to buy researched products from the companies that have developed them "is thought perfectly reasonable", implies that in their view, this is not exploitation.

'Scientific' value diversity

Within the STS field, a consequence of viewing science as socially constructed is that the distinction between 'facts' and 'values' is often viewed as non-existent. In a similar way, one of the central themes in van Asselt (2000) is that all arguments involve values. Therefore, also

[9] See Kemp, P. 1996, chapter 2 for a discussion of this concept. .
[10] Nuffield Council on Bioethics 1999; p. 96

scientific controversies, such as within the bioscientific community, can potentially be viewed in light of 'value diversity'. I have chosen to treat this instance of 'value diversity' separately, for two reasons:

Firstly, this view on scientific controversies can be contested. I will discuss this further below, after I have explained my interpretation.

Secondly, this instance of 'value diversity' falls outside the definition of variability as being ontological: here values can be seen as intrinsic to the scientific process, and a property of the analysts performing a study (thus being epistemological).

In 'scientific' value diversity, the issue relates to which scientific criteria are *evaluated* as appropriate in different contexts[12]. This can be seen as a way of 'framing questions'[13], in terms of a theoretical framework. Using different theoretical frameworks, researchers might interpret the same phenomena in different ways. Illustrative of this are the two levels of analysis in the bioscientific community (1.1): The researchers working on a micro-level focus on the inner workings of the cell and processes within the organism, whereas researchers working on a macro-level find ecological interactions more important. As I mentioned in chapter 3, this will influence the answer given to the other controversial issue I have identified within the biological community, whether GM crops should be viewed as 'significantly different' from conventional crops (1.2). The micro-level scientist might, for instance, only see a minor difference in the genetic composition of a GMO compared to a 'normal' organism ('one new gene amongst thousands'). Conversely, the macro-level scientist might see a trait in a novel organism that, when introduced into the environment, can disturb complex ecological interactions.

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[11] Cowie, A. 1989

[12] Cf. Tiles, M. and H. Oberdiek 1995

[13] This expression is based on Jasanoff and Wynne (1998), who argue that "issue framings do not flow deterministically from problems fixed by nature, [but] build upon specific models of agency, causality, and responsibility." (Jasanoff, S. and B. Wynne 1998; p. 5). A related expression can also be found in Bijker (1995), who talks about 'technological frames' (Bijker, W. E. 1995;, pp. 122-127). However, whereas these authors are talking about the practices and social frameworks within which an issue or a technology and the interpretation of these are situated, I have restricted it here only to the cognitive sense of the concept.

The answer to 'what is the right level of analysis' could perhaps be said to be an issue of 'lack of knowledge'. In van Dommelen (1999), it is a question of methodological analysis, and asking the right research questions. In this way, an analysis of what constitutes 'valid' evidence could potentially 'prove' one level right and the other wrong.[14] However, the position of van Dommelen is in itself a choice of level of analysis, and there will certainly be researchers opposing his claim to truth. Thus, the characterisation of this problem to 'lack of knowledge' presents some very serious problems, as it concerns how knowledge is gathered, and how to interpret knowledge or lack of such in the first place. Therefore, it seems that this question should be considered a source of uncertainty in itself. This is further supported by a common view held by 'outsiders' to the GM food debate: what makes them uncertain is that there are different researchers saying different things, often with a sense of certainty[15]. The consequence of this seems to be that science itself looses credibility.

The problem is slightly different for the interpretation of 'significant difference'. This problem cannot be considered as a source of uncertainty, as it depends partly on what level of analysis is chosen. However, the interpretation of 'significance' is also difficult to define to 'lack of knowledge', as 'significance' is an abstract term, with no agreed upon definition in this case. This can also be said about the analogies to exotic or conventional species that often are used to justify one interpretation over another. In many ways, the interpretation of 'significance' can be likened with the question if GM food is 'unnatural', except that in this case, it is scientific theories, not ethical or religious considerations that are supposed to form the basis. As with ethical or religious arguments, they can be discussed, but apparently not on the basis of empirical evidence.

Extending from these examples, several more of the controversial issues I have identified can be seen to stem, at least partly, from this source of uncertainty: The framework used to interpret the empirical material will influence whether it is counted as 'evidence', 'indications' or 'flawed research'. This is the case for many of the issues that are about environmental and human health concerns (2.1 – 2.4, 3.1 and 3.5), as well as the question if genetic engineering

[14] van Dommelen, A. 1999
[15] *E.g.* The Guardian 20/2 - 1999

increases crop yields (4.1)[16]. Therefore, I will also include these cases here. However, unlike the previously discussed issues, these issues can also be placed under 'lack of knowledge. For practical reasons, I will postpone a further discussion of these to the next chapter.

The classification of the above cases to 'value diversity' can be questioned, as it can be argued that the uncertain nature of the answer to these problems ultimately stems from 'lack of knowledge': Our incomplete information about different biological systems and their interactions creates uncertainties in how best to describe those systems. For instance, van Asselt (2000) states that the typology of uncertainty "does not consider disagreement and subjectivity as sources of uncertainty. It *explains* why disagreement and subjectivity is likely to occur in science." (4: 10). Thus, in this view, differences in 'scientific' value judgements are a result of[17] rather than a source of uncertainty.[18]

However, two points can be made, in addition to the already mentioned, that support the inclusion of 'scientific' value diversity in the case of the GM food debate:

Firstly, according to Smit (1995), uncertainty can be viewed as either the cause or the result of controversy: "In the first case, the uncertainty is shared by all the participants. The second type of uncertainty is the uncertainty to the outsiders, such as politicians. They are confronted with two positions, with different certainties, opposed to each other. Here the controversy results in uncertainty."[19] Similarly, Wynne (1995) describes uncertainty not so much as a measure of the unknown as a socially constructed state of mind about what we are willing to puzzle out[20]. Thus, the articulation of uncertainty can be seen to depend on whether there is or is not a controversy[21].

From a supply-side perspective, where bioscientists are included among the suppliers, this might be said to be irrelevant: researchers working from a particular level of analysis will

[16] Also the cases about antibiotic-resistance and allergens (3.3 and 3.4) could be included here. However, the controversy in these cases is more about the acceptability of an uncertainty that is more or less agreed upon to be relatively small.
[17] Or, in the terminology of van Asselt (2000), a *type* of uncertainty (van Asselt, M. B. A. 2000; 3A: 9-10)
[18] van Asselt, M. B. A. 2000; 3A: 9-10; 4: 10; personal communication.
[19] Smit (1995); in Bal, R. and W. Halffman 1998; p. 107
[20] Wynne (1995); in Bal, R. and W. Halffman 1998

interpret uncertainties in a particular way, with a particular outcome. Similarly, researchers working from another level of analysis will do the same, potentially with a different outcome. In this way, the resulting disagreement can be seen to stem from uncertainty. However, as a consequence of using the symmetry principle, my research perspective is as an outsider to the debate. From this perspective, the uncertainties that stem from such disagreement seem to have relevance.

Secondly, not to take this disagreement into account would significantly reduce the explanatory power of applying the taxonomy to the debate. This is because the differences between levels of analysis can be seen to be among the most fundamental to the debate, as I argued in chapter 3 (this is also illustrated by the number of cases identified above to belong (partly) to this source). It might be argued that this problem would be taken into account when analysing how the uncertainties are interpreted in terms of different worldviews, as depicted in Cultural Theory. This is the next step in the PRIMA approach van Asselt (2000) has developed. However, the worldviews described in this theory are simplified and in many ways stereotyped views of how people will perceive a problem. Thus, much of the richness and contextuality of the problem would be lost in such an account.

The sum of this leads me to stick to the above interpretation of 'value diversity', although the above discussion can indicate that this source of uncertainty needs a more elaborate definition.

I.iii) Human behaviour

Human behaviour has always been difficult to predict. Illustrative of this is research in social psychology on the consistency between attitudes and behaviour (what people say they will do and what they actually do). Often, the results have been ones of *in*consistency[22]. It is this unpredictable attribute of human behaviour that is the essence of this source of uncertainty.

I have chosen to restrict 'human behaviour' to a micro-level – that is, behaviour of individuals or small groups. Exactly where to draw the line between a small and a large group is problematic, but in my case it goes somewhere where groups become organised. This means

[21] Bal, R., personal communication.

that the behaviour of people in a shopping mall during some discount campaign would classify as behaviour of individuals or small groups, while consumers campaigning against corporate policy outside the mall would not. This brings up another problem, as it can be difficult to know when people act on their own or as part of an organisation. For instance, the behaviour of consumers and farmers can be crucial for the implementation of agricultural genetic engineering in new areas. If they choose to avoid genetically engineered products (and are able to do so), there will be no market for it. Partly, this will be the choice of individuals or small groups, as in the case of the ordinary consumer putting back a can of tomatoes after seeing the GM label. But, especially in the case of farmer organisations, there will probably be a significant influence on individual choices.

An even more serious problem is how to distinguish between values, attitudes and behaviour. Values and attitudes are important signposts for behavioural choices, making such a distinction artificial in many cases. However, behaviour can be seen as independent of values and attitudes in some cases, when the choices are made more or less unconsciously or as a result of ignorance[23].

Following the limited definition I use of behaviour, I have found only one argument in my collection that fits under this source. This is the point that was made in relation to the field trials conducted (2.1), if individual farmers can be expected to follow the safety rules imposed on them.[24]

I.iv) Social, economic and cultural dynamics

Social, economic and cultural dynamics can also be called societal randomness[25]. This source has a lot in common with the previous one, as the functioning of society ultimately depends on human action – however, this source is about 'behaviour' on a macro-level. The above-

[22] Stahlberg, D. and D. Frey 1996; pp. 224-232
[23] This is a source of uncertainty in itself (cf. chapters 2 and 5). However, here the case is about ignorance on an individual level. Conversely, ignorance as a source of uncertainty is about uncertainties on a general level (as can all of the sources of uncertainty in the taxonomy)..
[24] Potentially, this reasoning could be extended to many of the other questions in the debate. However, I have restricted myself to this one case, as this is the only one where this problem has been articulated.
[25] van Asselt, M. B. A. 2000; 3A: 8

mentioned influence of farmer organisations is a typical example of this. I have also included future regulations (that has not yet been implemented or been thought of) under this source of uncertainty. This is because regulations in my view can be seen as an expression of societal dynamics, as well as the result of such.

Many of the controversial issues classified as 'Third World arguments' fit in here. This is because the issues regarding these countries often are focused on the socio-economic effects of rDNA technology. A clear example of this is the question if rDNA technology will lead to an exploitation of poorer countries (4.3). In the case of 'terminator', the answer to this question will partly depend on the choices made by farmers and farmer organisations in Third World organisations. A problem that is particularly evident in this case, however, is whether they will have a real choice. A crude example is if the seeds with the 'terminator' genes are superior to other seeds: a small farmer might be faced with the choice between using the 'terminator' seeds or getting uncompetitive crops, which could mean the loss of his or her farm. Additionally, the answer to this question will depend on if companies are allowed to use this technology. There has been a lot of resistance against it[26], and demands that it should be banned.

On another level, this kind of pressure can move a company away from the use of a technology, regardless of laws and regulations. This is because the implementation of an unpopular technology can harm a company's reputation, which in turn can result in economic losses. One could hypothesise that these were just the concerns that moved Monsanto to put 'terminator' on ice.

Also in the case of 'biopiracy', there has been a lot of resistance. A consequence of this is that ongoing international negotiations seem to move in the direction of regulations that will restrict such possibilities[27].

Another question regarding socio-economic effects is the one about exclusion of poorer countries (4.4). As I mentioned in chapter 3, the argument has been made that little of the

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[26] *E.g.* Convay, G. 1999
[27] Bjerke, A. 2000

R&D in genetic engineering is done with a focus on the special needs of developing countries. However, this could change with new policies in industrialised countries (both in the private and public sectors). Both cultural and economic factors will play a part here:

Firstly, there has to be a change in willingness to use money and resources out of pure humanitarian reasons, as it will go to developments that won't give any direct economic profits.

Secondly, economic incentives may turn up in the future that aren't there now. For instance, some developing countries might become able to demand relevant technology developments in exchange for letting large corporations into their countries.

In the case of raw material substitution, this will depend, once again, on the action of the Western corporations. Here, the case isn't so much about the specifics of the regulatory framework they follow, however, because it is hard to imagine a prohibition imposed on industry for purely humanitarian reasons. However, consumer resistance, as in the above cases, could still move a company away from such developments.

The question if increased crop yields are necessary to solve the hunger problem (4.2) has relation to this source in a similar way. Here, part of the answer depends on whether it is possible to go the alternative routes of redistributing food and relieving poverty. As in the previous question, this will partly depend on the willingness of industrialised countries to help poorer countries. However, another thing is that the political circumstances in and between the poor countries themselves may play a part.

I.v) Technological surprises

This source has also been called technological randomness[28], and is about the unexpected consequences of, or unexpected developments in a technology. Using the GM food debate as an example, the commonly expressed feeling of unease and fear of unexpected consequences in the general public can partly be seen as emanating from this source. Especially since this is

[28] van Asselt, M. B. A. 2000; 3A: 8

such a young technology where much still is to be learned about the processes involved, there could be many uses and effects we cannot predict at this point in time. This also illustrates the difficult nature of this source: we *cannot know*, hence the name *surprise*.

When it comes to unexpected consequences, many of the controversies can fit under this source. More specifically, these are all of the environmental arguments (2.1 – 2.4), and the issues that have to do with allergens and pathogens (3.4 and 3.5)[29]. All of these controversies concern future outcomes that would be unexpected, at least by some of the participants in the debate.

Additionally, concerns about effects on the Third World could be placed under this source. However, in these cases, the consequences can be seen as depending on certain developmental paths, and the means to avoid them can at least be hypothesised. Therefore, the element of surprise isn't as evident as in the other cases.

As I mentioned under 'inherent randomness of nature', the environmental issues concern how GM crops will interact with the surrounding environment. When ecosystems are viewed as complex, involving an element of randomness that cannot be (completely) predicted, it seems that surprise consequences actually could be expected. However, the nature of these surprises is still uncertain, and doesn't even necessarily involve the issues that are debated.

In addition to the possibilities I described under I.i) in relation to the matters concerning allergens and pathogens (3.4 and 3.5), there is a possibility that bits of DNA can be combined into unwanted, functional units. Although these processes can be theoretically imagined, it seems it still would be a surprise if they really happened.

On the other hand, the hypothetical possibility exists that future technological developments could make it possible to reduce the uncertainties involved, for instance by making targeted insertions of transgenes into well-defined areas of genomes. Similarly, new technological

[29] Also, the question whether eating GM food can lead to an altering of your DNA (3.2) could go under this source. However, there is neither empirical material nor theoretical support for this notion. Therefore, I choose

developments might make it possible to prevent transfer of genes to weeds, limit negative effects on wildlife[30] and so forth.

Conclusions

In relation to the GM food debate, the most important sources of uncertainty in this chapter can be summarised in two categories: randomness (of nature, society and technology) and value diversity (including 'scientific' value diversity).

The first concerns the variability of the phenomena within which the GM food issue is situated. This will influence the predictability of the effects GM food will have on different areas of society and nature.

The other is about variations in *perceptions* of the GM food issue; both in terms of what is "worthwhile and desirable" and in terms of scientific theories and observations. In the first case, the implementation of genetic engineering itself is questioned. In the second case, what can be counted as knowledge or lack of such is questioned.

Counting only the aspect of value diversity termed 'scientific', both of these categories can be seen to influence what we can *know* about the effects of GM food. As such, variability can be

to go along with the argument that this is *very* unlikely – this notion seems more to be a product of fantasy than anything else (see also chapter 6).

[30] GURT (see chapter 3) has been proposed as one such technological development. By making the seeds infertile, it is argued that the possibility that GM plants will spread is eliminated. However, this is a contested claim, as some argue that the technology isn't completely reliable: the gene that makes the plant infertile might mutate or otherwise loose its effect after multiple generations.

seen as a source of lack of knowledge, as it makes perfect, certain knowledge anyhow unattainable[31].

[31] van Asselt, M. B. A. 2000; 3A: 8

Chapter 5: Lack of Knowledge

Apart from being influenced by variability, lack of knowledge is also about the imperfect internal state of scientific theories, hypotheses and empirical data[1]. As I mentioned in chapter 2, the subcategories of 'lack of knowledge' follow a continuum with an increasing degree[2] of uncertainty. The first three degrees of lack of knowledge have also been termed unreliability. Reliability is about *accuracy* in the data collecting process, as well as in the conclusions drawn. High reliability thus means that the data and conclusions can be trusted with higher confidence[3]. Conversely, unreliability is a source that will lower the confidence in the conclusions.

II.i) Inexactness

Inexactness has also been called metrical uncertainty, measurement errors and precise uncertainties[4]. The perhaps most obvious way of thinking about this source of uncertainty is that it is measurable, which means that the uncertainty can be placed within a percentage range. An example would be a statement common in statistical analysis: "there is less than 5% chance that these results are incorrect".

However, this category is also about uncertainties that arise from representing reality in terms of codified knowledge. Following a social constructivist perspective, although scientific 'facts' often are treated as objective and as mirrors of reality, they can never be more than blurred mirrors. As facts are made, not discovered, there will always be a component of human inadequacy that creates uncertainty in how accurate these facts are describing 'reality'. However, since a completely objective position is anyhow impossible, this source should be

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1 Implicit in this interpretation is the assumption that knowledge is codifiable. Strictly, this isn't true, as knowledge also can be seen to have a 'tacit' attribute, which can be defined as the uncodifiable know-how of some process or technique. However, in this taxonomy, the 'tacit' aspect is impossible to analyse in a meaningful way, for exactly the reason that it is uncodifiable. Therefore, in the following I will treat only the codifiable attribute of knowledge.

2 'Degree' should not be confused with 'magnitude' in this case: here it only refers to more or less fundamental uncertainties.

3 Hellevik, O. 1994; p. 159

viewed as uncertainty regarding whether research conclusions are accurately reflecting our *present state of knowledge*, rather than reality itself.

As the statement "we roughly know" [5] implies, this source is only valid for relatively small uncertainties. However, small uncertainties can still give rise to large controversies, depending on how important the issue is perceived to be. One consequence is that problems that fit under this source not necessarily are easier to handle than the others.

I have found several controversial issues that fit under this source: increased antibiotic resistance in gut bacteria (3.3), higher amounts of allergens (3.4) and the conversion of non-pathogens to pathogens (3.5). All of these possibilities are generally considered to be relatively unlikely – however, there are few that argue that there is *no* possibility. Similarly, the question regarding gene transfer to weeds (2.3) can be seen to belong to this source. However, this also depends on if, and in that case, to what degree transgenes are more easily spread than 'ordinary' genes. The answer to this question appears to be a matter of lacking or insufficient data, which is the topic of the next section.

II.ii) Lacking or insufficient data

Both of the sources 'lack of observations or measurements' and 'practically immeasurable' are about uncertainty in conclusions that arise because there isn't enough empirical material to support them. With new empirical material, the conclusions may be weakened or strengthened, but this cannot be determined before the data is actually collected and analysed. This means that, although certainty about an issue can never be fully accomplished, new supporting material can potentially reduce the uncertainties involved[6].

[4] van Asselt, M. B. A. 2000; 3A: 9
[5] Ibid.; 3A: 9
[6] This doesn't mean that more knowledge inevitably leads to a reduction of uncertainty – the opposite might also very well be the case. However, as I formulate it here, *supporting* (and the absence of contradicting) material can reduce the uncertainties involved.

Lack of observations or measurements

This particular category concerns data that is possible and feasible to collect, but that for some reason hasn't been[7]. An example is when there has been too short time to make empirical observations based on new theoretical material.

Practically immeasurable

In contrast to the previous source, this one concerns data that in principle can be measured, but not in practice[8]. The most common reasons for this are that the measurements required would be too expensive or too lengthy (or both). Therefore, this source produces uncertainties that cannot be reduced, as the required measurements will not be performed.

In addition to influencing the magnitude of controversies stemming from 'inexactness', the perceived importance of the issue at stake will also have an impact on what is considered as 'practically immeasurable'. For instance, if the issue is perceived to be relatively unimportant, even small time-scales or low costs may be enough to discard an empirical examination as 'immeasurable'. Furthermore, the perceived status of the theories or conclusions under question will have an impact: Few people would want to use time and resources on testing something they perceive to be far-fetched or unlikely, or conversely, on something they perceive to be adequately confirmed by earlier research.

Because of these influences, these two sources are hard to separate in many cases. Therefore, I have chosen to treat them as one in this analysis.

Illustrative of the above point are three of the controversial issues I have found to fit under either of these sources: the amount of herbicides and pesticides (2.2), gene transfer to weeds (2.3) and adverse effects on wildlife (2.4). These are connected with the controversy about the field experiments already conducted (2.1), as some argue that these deny the possibility of either of the other possible consequences. Following the view that these aren't good enough, however, there would be a requirement for other field experiments that are lengthier, and

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[7] van Asselt, M. B. A. 2000; 3A: 9
[8] Ibid.

consequently, more expensive. These experiments are in this view both missing and practically feasible. However, following the other view means that long-term field trials would be a waste of time and money, with a possible result that such field trials would be treated as 'practically immeasurable'.

Another point has been made that field trials in general pose a risk to the environment. This particularly applies to trials that aren't 'field containments', and thereby have the possibility to 'contaminate' surrounding vegetation. To some, this means that both field trials and GM crops should be banned altogether. What's more, even the field trials today, which are fairly well controlled, are strongly protested against, as shown by the many recent demonstrations in UK where tests crops haven been destroyed[9]. Both of these points could be used as reasons to deem more extensive field trials as untenable.

The Pusztai case (3.1) is another controversy that can fit under these sources in a similar way. There have been many demands for a repetition of his research, to find out if the conclusions could have some merit. Here, the issue is not so much about time and money, as the trials only extended over 10 weeks. The problem is more related to the research methods used. In a larger context, a common question in the debate is why GM food isn't subjected to the same tests as new pharmaceuticals. However, the standard procedure of testing medicines is to feed laboratory animals 100-1000 times the likely intake of the medicine. Provided that the food product in question would be used in the same amounts as other food products, this is not possible, as it would require a one-sided diet that would have profound effects on the animals' physiology[10]. The same problem has been pointed out in the research done by Pusztai: feeding the rats a one-sided diet of potatoes can be one of the reasons for the observed effects[11]. One could of course ask if it would not be possible to balance the diet by adding nutrients to the GM food, and this may be one of the reasons behind the demands for longer-term feeding trials.

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[9] *E.g.,* BBC News 16/6 - 2000; 4/9 - 2000; 28/8 - 2000; Myers, K. 1999
[10] Nuffield Council on Bioethics 1999; p. 34
[11] Pusztai changed the diet during the trials by adding nutrients. However, this was one of the reasons for rejecting the conclusions: changing research conditions during a controlled experiment introduces a number of uncertainties in the results.

The above discussion notwithstanding, a case that seems to be more belonging to 'lack of knowledge' than 'practically immeasurable', is the one about the monarch butterfly, where *Bt* corn pollen were proposed to have adverse effects on the larvae (under 2.4). As depicted in chapter 3, the absent effects on black swallowtail larvae are often used as a counter-argument in this case. Here, the controversy concerns the generalisability of the conclusions. The butterflies in question are two different species, and the validity of using the conclusions for one of them on the other can be questioned. On the other hand, the research on the swallowtail larvae was conducted in the fields in addition to in the laboratory, which means that these results may be more valid for the real situation than the monarch case. A potential solution therefore lies in conducting field studies with monarch butterfly larvae.

As I mentioned in chapter 2, the last four degrees of lack of knowledge are also termed structural or systematic uncertainty. These are more fundamental: Whereas unreliability is about the inaccuracy in observations and the conclusions drawn, structural uncertainty is about how theories that underlie or are induced from these observations and conclusions are used and about theories that cannot be confirmed or discarded with observations or measurements.

II.iii) Conflicting evidence

This source is about problems that arise when data sets are available, but the observations allow room for competing interpretations[12]. The reason for such competing interpretations can be traced back to 'scientific' value diversity: how the data is viewed can be seen as a result of how questions are framed.

Potentially, many of the cases I have described could be seen to belong to this source of uncertainty. However, I have restricted myself to cases where there have been collected substantial amounts of data that directly address the question asked. This means that there only are two controversial issues in the debate that fit in: the question if the field trials 'prove'

[12] van Asselt, M. B. A. 2000; 3A: 9

that GM crops are safe to the environment (2.1) and the question if genetic engineering increases crop yields (4.1). In both of these cases, the answer depends on how the question is framed: in what context the field trials are placed and in what value is placed on the plants growing beside the main crop in the field.

II.iv) Ignorance and indeterminacy

The three highest degrees of 'lack of knowledge' are all about *uncertain uncertainties:* "we don't know what we don't know", "we will never know" and "we cannot know". These sources of uncertainty all have a problem in common. This is that they partly concern developments in scientific knowledge that we don't know about yet, which makes the concerned issues in many ways indeterminable. A consequence of this is that the classification of controversial issues to any one of these sources is very difficult, as this really only can be done in retrospect (see also the comments under 'reducible ignorance'). Therefore, I have chosen to treat them as one in the analysis. First I will, however, give a more detailed description of them each.

Reducible ignorance

Reducible ignorance is about "processes and interactions between processes that we do not observe, nor theoretically imagine at this point in time, but probably in the future"[13].

According to Shackley and Wynne (1996), postponement of the solutions to problems to the future is a common tactic in the context of research used for decision-support. From the researchers' viewpoint, this can be seen as both a way of ensuring continued financial support and a way to reinterpret uncertainties that really belong to the next two sources (indeterminacy and irreducible ignorance) to create a false sense of certainty in the research that is planned for the future. From the decisions maker's point of view, postponement into the future can help to justify salary posts devoted to the research, as well as to create an impression that something is done, without having actual results to show to. However, to say that problems will be solved in the future is by no means a certain affair, as implied in the statement "we

[13] Ibid.

don't know what we do not know"[14]. This is reflected in how researchers on scenarios[15] internally may treat their descriptions with "a mixture of irony and ritual", even though decision makers treat them as reasonably robust and read them rather literally.[16]

Because of these problems, an unambiguous categorising of uncertainties to this source is quite impossible, and should be treated with great caution.

Indeterminacy

In contrast to 'reducible ignorance', indeterminacy is about processes of which we understand the principles and laws, but which can never be fully predicted or determined[17].

A clear example of this is uncertainty in historical analyses. Even in cases where the historical material is abundant, there will be a component of indeterminacy, as an event never can be fully captured in accounts of that event. As a result of this, events are often interpreted differently by different sources, and determining what source(s) is the most reliable will often be impossible.

As mentioned above, also the prediction of future events can be viewed as belonging to this source. This is especially the case with complex systems, such as the stock market, the global climate and, as argued earlier, ecosystems: the chaotic nature of these systems, and a vast number of identifiable and unidentifiable variables, make an unambiguous prediction of future outcomes impossible.

[14] Ibid. (emphasis added).
[15] Scenarios are 'archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present and future developments'. van Asselt, M., C. Storms et al. 1998; p. 10
[16] Shackley, S. and B. Wynne 1996; pp. 283-287
[17] van Asselt, M. B. A. 2000; 3A: 9

Irreducible ignorance

The highest degree of 'lack of knowledge' is about processes and interactions between processes that cannot (or not unambiguously) be determined by human capacities and capabilities[18].

Depending on the degree of missing material, the above example on uncertainties in historical analyses can also be placed under this source. For instance, analyses of events that happened before humans evolved a written language, or for which there are no written records, would go under this source. Similarly, the prediction of future events can be seen to belong to this source, depending on how the 'understanding of principles and laws' is interpreted. For instance, it can be argued that we will never fully understand the principles and laws of ecosystems and their processes, leaving a component of irreducible ignorance.

In the GM food debate, it is evidently the prediction of future events and outcomes that constitutes the problem, as there have been few developments yet, but many possibly to come. As mentioned in chapter 2, our inability to predict future events, outcomes and consequences mainly has its source in variability. The variability, or *randomness* of events creates an uncertainty, and to a certain degree also an incapability, to foresee or dismiss future events. Thus, all of the cases I have categorised under natural, behavioural, societal or technological randomness (I.i, I.iii, I.iv and I.v) can also be seen to fit under these sources of uncertainty[19].

Value diversity (I.ii) is a special case. In the issues I have identified, there doesn't seem to be a clear link between this source and ignorance and indeterminacy. However, when it comes to what is "worthwhile and desirable", this will have an impact on whether genetic engineering for food, as a whole or partly, is implemented at all: very strong and negative public attitudes can mean life or death for a commercial enterprise. So, for the company or politician trying to introduce such food, this will create an uncertainty in the outcome, which cannot be eliminated with more knowledge.

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[18] Ibid.

In the case of 'scientific' value diversity, this can be said to have an influence on what is classified as belonging to ignorance or indeterminacy in the first place: For instance, claiming that the field experiments already conducted are good enough (2.1) can be seen to be a statement in the direction that this is a case that is determined, and thus doesn't belong to 'lack of knowledge' at all.

Finally, also the question if genetic engineering increases crop yields (4.1) can be seen to belong to these sources of uncertainty. This is because some of the arguments in this case are about what yields GM crops, as well as conventional and traditional crops can give in the future.

Conclusions

The discussion in this chapter has given two main results:

Firstly, the taxonomy of sources of uncertainty has been adjusted both on the level of unreliability and the level of systematic uncertainty:

In the first case, 'lack of observations and measurements' and 'practically immeasurable' have jointly been defined as 'lacking or insufficient data'. The main reason for this is that an unambiguous categorisation to only one of these sources would involve evaluative judgements of the 'facts', which would be in conflict with the research perspective I have taken.

In the second case, 'reducible ignorance', 'indeterminacy' and 'irreducible ignorance' have been merged to 'ignorance and indeterminacy'. This is because all of these sources, when viewed in relation to the GM food debate, involve uncertainties about the future, and imply different future developments in knowledge: a categorisation to any one of these source is therefore as good as impossible.

[19] These cases are: 2.1 – 2.4, 3.3 – 3.5, 4.2 – 4.4

Secondly, the most prevalent sources of uncertainty when used on the GM food debate are precisely those that are adjusted. When it comes to 'lacking or insufficient data', most of the cases concern the environment. This has a clear connection to the field studies that have been performed: when viewed as inadequate, these represent a huge gap in the knowledge base for evaluating potential environmental impacts, as there are few studies performed with an alternative approach. In the case of 'ignorance and indeterminacy', three out of five main categories in the debate are represented. This can be viewed as a direct result of the sources of uncertainty that I summarised in the category 'randomness' in the previous chapter, belonging to 'variability': 'natural randomness', 'societal randomness' and 'technological randomness'.

Table 1 on the next page gives a summary of how I have classified the different controversial issues in relation to the taxonomy of sources of uncertainty.

	Sources of Uncertainty / Controversial Issues	I.i	I.ii		I.iii	I.iv	I.v	II.i	II.ii	II.iii	II.iv
			a	b							
		Natural randomness	*Value diversity*	*Scientific value diversity*	*Human behaviour*	*Societal randomness*	*Technological surprises*	*Inexactness*	*Lacking or insufficient data*	*Conflicting evidence*	*Ignorance and indeterminacy*
1.1	*Level of analysis?*			X							
1.2	*Difference GM crops and conventional crops?*			X							
2.1	*Field studies: GM crops safe for the environment?*	X		X	X		X		X	X	X
2.2	*Amount of herbicides/pesticides?*	X		X			X		X		X
2.3	*Gene transfer from GM crops to weeds?*	X		X			X	X	X		X
2.4	*Adverse effects on wildlife?*	X		X			X		X		X
3.1	*Pusztai: GM food dangerous to human health?*			X					X		
3.2	*Eating GM food: altering of DNA?*										
3.3	*Marker genes: more antibiotic-resistance?*	X						X			X
3.4	*Higher amounts of allergens?*						X	X			X
3.5	*Conversion of non-pathogens to pathogens?*			X			X	X			X
4.1	*Increased crop yields?*			X						X	
4.2	*Increased yields necessary to solve hunger problem?*					X					X
4.3	*Exploitation of poorer countries?*		X			X					X
4.4	*Exclusion of poorer countries?*					X					X
5.1	*GM food 'unnatural'?*		X								
5.2	*GM: mechanisation of nature, and is this bad?*		X								

Table 1: Summary of analysis of the GM food debate in terms of sources of uncertainty

Chapter 6: Controversy and Uncertainty

The description and analysis of the GM food debate in the previous chapters has given two main results:

Firstly, the controversy has been defined and categorised in terms of sources of uncertainty. In the first step, the main themes in the debate were described in terms of the opposing and diverging viewpoints on the specific issues. From this, it should be clear that the 'facts' of the debate don't give a straightforward answer. In the second step, the debate was described in terms of what makes these 'facts' uncertain and thereby open to dispute. From this it is possible to identify issues that are more fundamental and/or complex than others.

Secondly, the taxonomy used has been refined, interpreted and adjusted to the specifics of the empirical setting. A sub-category has been added to 'variability', and five of the categories under 'lack of knowledge' have been reduced to two.

While the conclusions regarding the taxonomy partly were given after each of the analysis chapters, I have postponed conclusions regarding the fundamentality and complexity of issues to this chapter. Therefore, the last point will be devoted the most attention in this chapter.

Defining the controversy

The most commonly referred to issues in the GM food debate are already described in chapter 3. However, with additional findings from the analysis in chapters 4 and 5, some of the issues can be identified to be more important or difficult than others: both in terms of how they influence other issues, in terms of if they can be debated in terms of scientific evidence, and in terms of more or less fundamental uncertainties involved.

Fundamental issues

Some of the controversial issues can be said to be more fundamental than others, in that they influence other issues in the debate. In particular, this can be said about the levels of analysis used (1.1) and the interpretation of 'significant difference' (1.2). Also the ethical and religious considerations (5.1 and 5.2) can be regarded as fundamental, but in another way: here the question is about the implementation of genetic engineering itself, and about intangible consequences to our relation with nature and God.

In the following, I will explain this more closely.

Levels of analysis

> *"Sheer confusion has been the GM debate's defining trait. The cheap shot is to blame tabloid colleagues for casting all scientifically amended produce as 'Frankenstein Food' (…). Britain's cartoonists have tagged along, imagining tomatoes with little faces, cucumbers with legs, and courgettes marching like zombies into the night. We can blame them if we like, but the problem is a shared one. GM foods have become a source of semi-hysteria this week partly because so many of us are scientifically illiterate. Unless all scientists agree with each other, thereby allowing the rest of us not to bother our heads, we are reduced to a state of gormless darkness."*
>
> \- Leader, The Guardian, 20/2 - 1999

The above quote tells a lot about the first of these issues, the use of different levels of analysis. Although many of the public can be said to be well informed about scientific advance and new technologies[1], according to Beck (1992) our 'risk society' makes it increasingly difficult to identify hazards. This makes us increasingly reliant on the 'sensory organs' of science – theories, experiments and measuring instruments – to be able to pinpoint and visualise those hazards.[2] However, when these 'sensory organs' are sensing different things, as in the case of researchers working on different levels of analysis, the conclusions will also be diverging. In the analysis, this has been shown to be especially apparent for the environmental issues and concerns about human health, as they evolve directly around the scientific 'facts' of the biological community. To the outsider, the mere presence of these diverging viewpoints will result in confusion, in who to believe and trust, or as the ultimate consequence could be, whether to trust anyone at all.

The two main levels of analysis can thus be viewed as fundamental to the debate, as their presence can be considered a source of uncertainty itself.

[1] ESRC Global Environmental Change Programme 1999; p. 4

'Significant difference'

As I mentioned in chapter 3, the claim that GM crops differ insignificantly from conventional crops is one of the most common arguments in the debate. Specifically, it can be connected to the controversies surrounding gene transfer to weeds (2.3; herbicide-resistant genes are common in nature already), marker-genes and antibiotic-resistant bacteria (3.3; other agricultural practices are much worse), the use of the 'terminator' technology (4.4; similarity between 'terminated' seeds and F1 hybrids) and if GM food is viewed as 'unnatural' (5.1; 'unnatural' implies significant difference). Thus, this issue is fundamental in the sense that it is applicable to every major topic in the debate.

Issues that cannot be defined to 'lack of knowledge'

Both of the above issues, as well as the ethical and religious considerations, have a special place in this analysis: these issues cannot be seen to have both a component of variability and of lack of knowledge, as is the case with the other issues in the debate. The reason for this is that the dispute is on a level that is beyond the debate on empirical evidence: in the case of levels of analysis used, they are *creating* different empirical evidence. In the case of the interpretation of 'significant difference' and the ethical and religious considerations, the definition of the terms in question is either not agreed upon or is not possible at all. Thus, none of the arguments related to these issues can be confirmed or refuted with reference to empirical research.

<u>Main themes, randomness and fundamental uncertainties</u>

As I have argued throughout the thesis, the complexity of issues can be viewed as the main reason that there always is a component of irreducible uncertainty in our knowledge about such systems. From this, and a quick look at table 1, it might be argued that in the GM food debate, the environmental issues involve the highest degree of complexity. This is because these issues involve both natural and technological randomness, that directly give rise to ignorance and indeterminacy. The main reason for this complexity probably lies in natural randomness, in the form of processes and interactions in ecosystems. This randomness will, in

[2] Beck 1992; in van Dommelen, A. 1999

turn, have an influence on technological randomness, in the form of unexpected consequences.

Following this it might be argued that human health issues involve a lesser degree of randomness, and thus a lesser degree of ignorance and indeterminacy, as they are only classified to technological randomness. As I argued in chapter 4, the more isolated nature of human and animal physiology makes these issues less compatible with natural randomness. However, there is nothing that points in the direction of technological randomness being any less 'random' than its natural counterpart. Therefore, no conclusions should be drawn about the degree of ignorance and indeterminacy. The only conclusion that can be drawn is a tentative one, and this is that human health issues involves less complexity because of their higher degree of isolation.

This seems to be in contrast to the last source of uncertainty involving randomness. Third World arguments have mainly been associated with societal randomness in this thesis. As I have defined this source of uncertainty, involving policy decisions, this might be an aspect of randomness that gives rise to a less fundamental degree of uncertainty. In these cases, the consequences can be seen as depending on certain developmental paths, where the element of surprise or ignorance isn't as evident as in the other cases. For instance, both Oxfam (1999) and the Nuffield Council on Bioethics (1999), stresses the importance of political intervention if GM crops are to have a positive effect in these countries, and the suggestions are very similar: more R&D focused on developing countries, more money to governmental and otherwise independent research institutes and the establishment of a strong international regulatory framework.[3]

<u>'Less' uncertain issues</u>

Conclusions regarding the *magnitude* of uncertainty are problematic in this thesis: this is because most of the issues are complex, involving a number of different types of uncertainties that not necessarily are comparable. However, some cases are possible to distinguish out as less problematic, at least in some respects. These are issues where the arguments from one side in the debate are supported by little or no empirical and theoretical work, where more empirical seems likely to resolve the issue, or where the reason for concern is removed:

One of the cases in the debate doesn't seem to fit under any of the sources of uncertainty. This is the question if eating GM food can alter ones own DNA (3.2), which the scientific community seems to be unanimous in rejecting. However, a person can still believe this, based on his or her subjective judgement (or individual 'framing' of the questions), and maybe as a consequence of a general mistrust of the scientific community. This is part of a more general problem: preliminary research and unsubstantiated claims sometimes make it to the headlines of the media. A possible result is that what is considered as 'facts' in parts of the general public not necessarily is considered as such within the scientific community. In this case, there is apparently no uncertainty at all as I have defined it, just 'lack of knowledge' on an individual level (which is not included in the taxonomy).

Also the Pusztai case (3.1) can in some respects be said to be less uncertain, in that the scientific community seem to agree, by and large, that the experiments are rather inconclusive. However, there still seems to be uncertainty about the claimed effects, as more experiments have been demanded.

Finally, the cases regarding the monarch butterfly (under 2.4) and antibiotic- resistance (3.3) seem to have a good chance of being resolved in the near future. In the first case, this is because there are field experiments conducted with monarch butterfly larvae currently being performed. Although there still can be questions asked about the methodology of the field experiments, at least this will resolve the debate about the generalisability of the conclusions. However, the question if GM crops will have adverse effects on wildlife will still be largely unanswered, as the monarch butterfly is only a small part of this wildlife. In the second case, there seem to be willingness in the industry to remove the marker-genes coding for antibiotic-resistance from GM food products, or to use alternative marker-genes. If this happens, the cause of the controversy will disappear.

[3] Nuffield Council on Bioethics 1999; Oxfam 1999

Prevalent sources of uncertainty and the debate as a whole

Some sources of uncertainty are more prevalent than others in relation to the issues I have described. These are 'value diversity' (including the 'scientific' subcategory) and 'ignorance and indeterminacy':

In the first case, there are questions asked about the implementation of genetic engineering itself, as well as about the definition of knowledge as well as lack of such. Thus, in concordance with the definition of some of the issues categorised under this source of uncertainty, 'value diversity' can be seen to influence most parts of the debate.

In the second case, the categories are influenced by natural, societal and technological randomness, and thus capture the consequences of these sources of uncertainty in one category.

Summary of adjustments to the taxonomy

Figure 2 on the next page summarises the changes that have been made, as well as which sources of uncertainty that are more prevalent in the debate (the less prevalent categories are excluded):

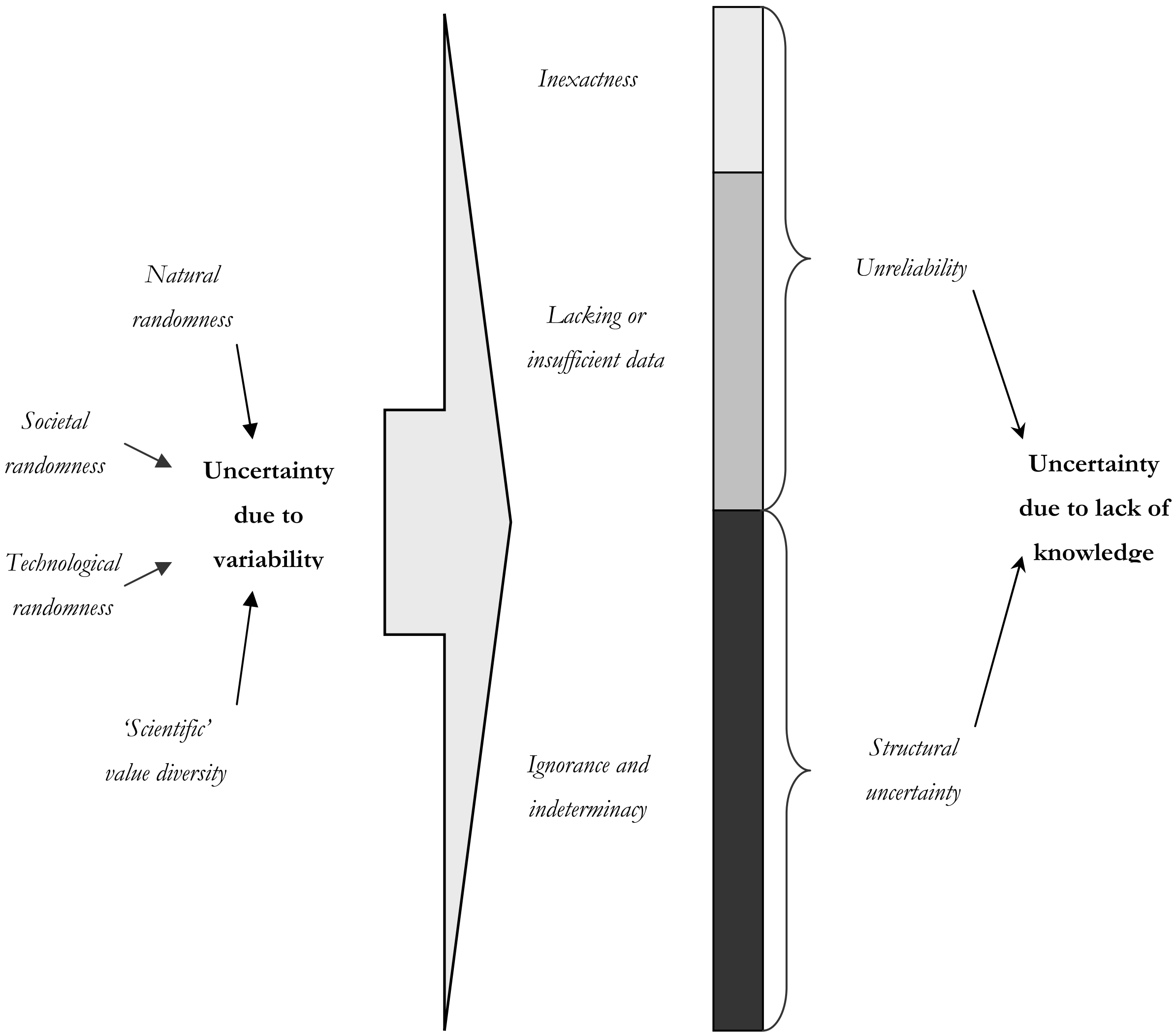

Figure 2: Taxonomy of sources of uncertainty in relation to the GM food debate

Uncertainty and risk perception: additional considerations

The explanatory power of an analysis in terms of sources of uncertainty is limited, as a controversy doesn't arise from uncertainty alone: no matter how large the uncertainty, there will not be a controversy unless there also is a perceived *risk*. Conversely, if there is a perceived risk, even small uncertainties can lead to controversy. This is most clearly illustrated by the issues categorised to 'inexactness' and 'lacking or insufficient data'.

In the first case, an example is the possibility that marker-genes in GM food will lead to higher antibiotic-resistance in gut bacteria (3.3) is generally considered to be relatively small compared to the effects of other agricultural practices. However, to some, this small increase is enough to ban the use of marker genes conferring antibiotic resistance in GM food products. To others, the increase is interpreted to be so small that it is negligible. Thus, the controversy in this case is not so much related to the (relatively certain) answer given, but how important the increase is perceived to be.

In the second case, low perceived risk may lead to something being defined as 'practically immeasurable', meaning that the uncertainty cannot be reduced.

Potentially, there are several more issues that would need an additional explanation in terms of risk perception. However, since this is not the aim of this thesis, I will restrict myself to the above cases.

Implications: radical uncertainty and participation

This thesis has shown that the GM food issue is a *complex* problem:

Firstly, there is not one problem, but a set of interrelated problems. I have treated five different themes in the GM food debate that range from the discussion of bioscientific facts to our relation with God. All of these issues can be seen to be interdependent: all of them concern potential impacts of GM food on society and nature, and all of them will influence public attitudes to GM food. In the case of bioscientific 'facts' in environmental and human health issues there has also been a discussion of context-effects: the insertion of a transgene into a genome and the placing of a GM plant in an ecosystem can have unexpected effects on these systems, as these systems involve intricate and interdependent processes with, in the first case, other genes and in the second case, with other organisms and nature.

Secondly, in the attempt to give certain answers, the bioscientific community itself adds to the uncertainty and complexity of the problem.

Thirdly, large parts of the debate evolve around *future* developments and impacts. The future is never determinable: there can only be guesses made, where some are more likely than others.

Finally, because of the above points, there are a number of *radical* uncertainties when it comes to predicting the impact of GM food: these are uncertainties that cannot be reduced.

From these points, there are two main implications that can be drawn about the assessment of GM food and its potential effects:

One, that science cannot provide certain, straightforward answers, and in some cases cannot provide the answers at all. This has to be acknowledged, both in the scientific, the political and the public sphere.

Two, because of this, public participation is necessary to make decisions about the introduction of GM food.

In the following, I will examine these implications more closely.

Acknowledgement of radical uncertainties

During the whole analysis, I have identified uncertainties in the diverse issues in the GM food debate. In some ways, this could imply that I was taking a stance in the debate: for instance, those who argue that there are uncertainties involved when GM crops are placed into the environment are usually also researchers working on a macro-level of analysis. However, there are several reasons for the inclusion of these issues in the conclusion.

One is that the ‘certainty’ of micro-level analysists can partly be an illusory one. The reason that micro-level analysists seem more certain could be that focusing on a micro-level means a smaller number of variables to take into consideration. However, this only explains part of the problem. For instance, as I argued in chapter 4, the effects of a transgene on a genome (which is a problem for the micro-level of analysis) can be said to be complex, and thus involve a number of uncertainties. Following an STS perspective, an obvious, alternative place to look would be in the social context these researchers are situated in. Shackley and Wynne (1996) has done this in relation to climate researchers working as advisors for policymakers, who can be seen to be in a similar situation to the researchers in question here. According to these authors, the relationship between policymakers and scientific advisors is characterised by so-called boundary ordering devices. This term refers to the special form of discourse that exists between these two groups that can be seen to maintain. Of interest here is that this discourse leads to a reduction the actual uncertainty acknowledged by the scientists when these are presented to the decision-makers. Thus, what is considered uncertain knowledge within the scientific community might not be considered as such for the people that use this knowledge to make decisions.

Another reason for the inclusion of these issues is that the conflict between the different levels of analysis can be viewed as artificial. In van Dommelen's (1999) words, in the GM food debate concerning bioscientific issues, there is a lack of relevant research questions - the dispute between micro- and macro-level analysts, he argues, is an *artificial* controversy. Both levels of analysis are relevant for the question of the biosafety of GM food, as long as context-effects are considered. Thus, the problem isn't necessarily one of appropriate levels of analysis, but of the acknowledgement of uncertainty and complexity on both levels.

Finally, analysis on a micro-level is the major means of assessing GM products today, as no ecologists have been included in advisory committees[4]. The above points supports the inclusion of such macro-level scientists in advisory committees, which in any case seems the right thing to do considering that they claim to have relevant knowledge of the problems in question.

[4] ESRC Global Environmental Change Programme 1999; p. 5.

Public participation

The second main implication given above was that the public participation is necessary to make the right to be included in the decisions made about the introduction of GM food. This is both because there are issues where researchers cannot provide the answers, most notably ethical and religious considerations, and because there are a number of issues where even the best of research cannot provide certain answers. Considering the potential detrimental impacts the introduction of GM food might have, the public should have the right to be a part of those decisions. Furthermore, in the issues concerning the Third World, participation is required on an international level, in that developing countries should be included when making decisions about international regulatory frameworks.

Appendix 1

rDNA technology – basic concepts and principles

DNA (Deoxyribonucleic Acid) is the hereditary material that is found in every living cell. In any particular multi-cellular organism, each cell (usually) contains an identical copy of a very long stretch of this molecule, referred to as a *genome*. It consists of a double helix of two complementary strands that are long chains of deoxy-ribose (a sugar) with four different bases, adenine (A), thymine (T), cytosine (C) and guanine (G), attached to them. These strands are coupled in such a way that C always is matched with G, and A always with T (these couplings are called a *base-pair*). This makes it possible for two identical copies of the DNA molecule to be made during cellular division, when each strand in the original molecule acts as templates to build the complementary strands.

More importantly, parts of the strands also act as codes for the production of various other molecules, usually proteins[1]. These parts are called *genes*, where long stretches of bases are ordered in a particular way (different for each gene). While a DNA molecule contains many genes, usually between 50 000 - 100 000 in a higher organism such as a plant or an animal, most parts are thought to be non-coding. Some of these parts are regulatory sequences, which act as binding sites for various molecules that control the expression of genes (*i.e.* in what amounts and how often the gene product – in the above example, a protein – is made)[2]. However, large parts are so-called 'junk DNA' that is thought to be non-functional by-products of evolutionary processes. Moreover, in any particular cell in a multi-cellular organism, many of the genes are 'shut off' permanently, depending on what function the cell has. This means that most of each cell's DNA actually is thought to have no function.

In higher organisms, such as plants and animals, reproduction usually is sexual. This means that half of the genetic material in the offspring is provided by the 'male' and half by the 'female'. In this process, genetic material is *recombined* in novel ways, with the result that siblings never are completely alike. This variety is used in traditional breeding, to produce plants or animals that are more suited for human purposes. By letting only offspring that have the most favourable traits reproduce, generation after generation, an organism can be changed quite dramatically, as illustrated by a comparison between any domesticated species and its wild relatives.

Thus, also normal reproduction involves genetic recombination, and can produce large changes. However, this recombination is limited to within a species, as the genes that are recombined cannot be too dissimilar for the process to occur. Also, the breeding of a new variety is time-consuming, usually a matter of several generations, and this is more profound the longer the life span of the organism is.

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[1] Proteins are very complex molecules that act as 'building blocks' in a cell, or that have important functions in (most) cellular processes, such as metabolism.

[2] In some definitions of genes, these regulatory sequences are included as part of the gene. However, for ease of explanation, I have described them apart.

Recombinant DNA (rDNA) technology, however, has made it possible to recombine genetic material from totally unrelated species, such as a bacteria and a plant, in only a single generation. The technique essentially consists of 'cutting and pasting' stretches of DNA, using bacterial enzymes. As DNA has the same composition in every living organism, these stretches can be taken from any species and be pasted together with stretches from any other species.

Nonetheless, there are some limits to this technique, too. For instance, with today's knowledge and technology, the 50-50 combination of the genes from, let's say, a mouse and an elephant would produce no viable result. This is because many of the genes in a functioning organism interact in very complex ways, and differently so for different species. The usual procedure is to identify one or more genes that produce a certain substance in one organism, and then transfer only those genes to another organism. This way, a plant can for instance be made to produce a pest-fighting substance, which normally is produced only by bacteria.

The transfer of genes can be done in several ways, but a common one when it comes to plants is to use a natural mechanism found in the bacterium *A.tumefaciens*. This is a bacterium that transfers parts of DNA to the genome of the plant it is infecting, that normally leads to tumours. The bacterium used in rDNA technology has had its tumour-inducing properties removed, and instead the desired gene inserted.

The gene that is inserted into a genome with rDNA technology is in a construct called a *transgene*. This usually consists of the desired gene, a promoter-sequence that enhances the expression of the gene and a *marker gene*. This last bit is only there to identify the selection of successfully transformed cells. The marker genes used today code for antibiotic-resistance: when the cells are grown on a medium containing antibiotics, only the transformed cells survive.

Genetically modified food today

GM food has been around for some time already: the first plant was genetically modified in 1982, and the first commercial GM food product (the 'flavr savr tomato', genetically modified for longer shelf life) was released in 1994[3].

To date, there are very few developments of GM food that involve animals. Notable exceptions are rBST, a hormone produced by genetically engineered bacteria to raise the production of milk in cattle[4], and a recently developed Salmon that grows much faster than normal varieties. However, the salmon have yet to be approved for commercial use. A much larger part of GM food products involve micro-organisms and plant crops. The first type is mostly bacteria and yeast genetically modified to produce food additives (*e.g.* vitamins), and food processing enzymes, such as chymosine used in cheese making and several enzymes routinely used in livestock feed. The second type is plants genetically modified to enhance

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[3] van Dommelen, A. 1999; p. 24
[4] Cf. Gottweis, H. 1998

agricultural production.[5] This is also the type of GM food products that have stirred up most of the debate.

The by far most common GM crops today are those with herbicide or insect resistance (approximately 71% and 22% of world production, respectively, in addition to 7% with both traits[6]):

Herbicide-resistant plants are genetically modified to survive herbicides that otherwise would kill them along with the weeds that are causing trouble. Herbicide-resistance makes the use of non-selective herbicides possible, which means that the farmer only has to do one round of spraying, instead of multiple rounds with selective herbicides that kill one particular type of weed at the time. Moreover, herbicide-resistant plants represent the first commercial use of genetic engineering on crop plants, and are among the few GM plants that are represented in Europe today.

A similar technique is modifying plants to produce their own pesticides. The most common of these are corn and cotton modified to produce *Bt* toxin, a family of insecticides usually produced by a bacterium (*Bacillus thuringiensis*). One of the purposes is to fight insect-pests that are difficult to control with chemical sprays - an example being the European corn borer that hides in the stalks of the plant.

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[5] OECD 2000; pp. 8-11
[6] James, C. 1999

Appendix 2

Additional Issues in the Debate

Here I have placed two issues I have worked on to some extent, but that I haven't included in the thesis. I have also mentioned some issues that seems to have relevance in the debate as a whole, but that I excluded at an early stage, and that therefore aren't described more than in a few key points.

Problems with modern agriculture: intensification or solution?

Ever since Rachel Carson published her book "Silent Spring" in 1962 there has been awareness that modern agriculture can have a significant, damaging effect on the surrounding environment. GM crops seem to have revitalised this debate, by some seen as an extension and intensification of modern agricultural methods.

The proposed alternative to modern agricultural methods is organic farming. There seem to be diverse working definitions of this, but a common factor is the desire not to use chemically synthesised herbicides, pesticides or fertilisers. Crop yields are usually lower than with modern agricultural methods (se, however, the discussion on yield measurements under (4.1)), but according to a recent report by The Soil Association the methods used are more beneficial for wildlife. The report showed how organic farming methods resulted in far greater numbers of birds, plants and other species on and around the farms than conventional methods.[1]

It has been argued that GM crops should not be considered an enemy to organic farming, but a natural ally – this is because of the argument that the amount of herbicides and pesticides are reduced with GM crops. However, if this argument doesn't hold water, as many of the organic farmers seem to believe, GM crops are as bad, or even worse than conventional methods.

Another attack on organic farming proponents is that the lower yields coming from organic farms will lead to a need for expansion of cultivated areas into surrounding areas, further reducing the space available for non-cultivated species. GM crops, it is argued, will lead to a more efficient use of the land already used for farming, and can even reduce the land needed, so that parts of the countryside can be given back to wildlife[2].

Labelling and consumer choice

According to the Nuffield Council on Bioethics (1999), the provision of choice to avoid GM food can in itself be considered as a good, in that it acknowledges a diversity of views[3]. However, this is not an uncomplicated matter. Firstly, it is argued that the only way to ensure that food

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[1] The Soil Association (May, 2000). "The Biodiversity Benefits of Organic Farming".

[2] Nuffield Council on Bioethics (1999)

[3] Ibid., pp. 9-10

doesn't contain GMOs is to trace the non-GM plants from the farm gate[4]. This is because there are no tests for products which originate from GM plants, but which do not contain GM DNA or proteins and are chemically identical to the product from the unmodified plant. Also, when the product does contain GM DNA, it is necessary to know at least parts of the transgene sequence to be able to identify it. This sequence may be held back as a trade secret by the producer, making testing very difficult[5].

This tracing, it is argued, will impose large costs on the producers. For instance, Argentina and Canada argue that this would increase handling, storage and transport costs by as much as 20%[6]. These costs could go further down the line to employees and consumers[7].

Secondly, even tracing from the farm gate cannot ensure that the food is 100% GM free, as long as there are GM crops grown nearby - the already mentioned seed accident illustrates this. According to BBC News, Jeffrey Smith, a US agricultural expert has stated that the mixing of GM and conventional seeds is probably widespread and impossible to prevent. The company where he is vice-president screens agricultural produce for GM material, and it found that more than half of 20 random samples of conventional seed taken from US distributors contained some GM seed[8].

Thirdly, even if there is a choice, there is a risk that it will not be a 'real' choice for everyone. This could happen if GM food becomes significantly cheaper than 'traditional' food, limiting the choice to those with a relatively strong economy[9].

Other issues

Economy (macro-level) and innovation

- Impact on national economies and national prestige in the industrialised world (EU: economic and technological back-lash in relation to the US if technology not implemented?)
- EU – USA trade conflicts
- Degrees of democratic control and the conditions for innovation ('strong democratic control + 'irrational fears' = death of innovation')

Farmer and consumer issues

- Large multi-nationals: undue power?
- Small farmers (industrialised countries) loose to the benefit of large corporations: technology adjusted to large-scale farming, farmers forced into a relation where they are being exploited ('terminator' technologies/ GURTs). Also:
- Consumers loose to the benefits of large corporations: few consumer benefits (price, taste, etc.) to date, fear that there will be none in the future. This in relation to unknown risks

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4 Ibid., p. 92
5 Ibid., p. 27
6 The Economist (1999). "Seeds of discontent". The Economist. 20/2 – 1999.

7 Nuffield Council on Bioethics (1999)
8 Kirby, A. (2000). "GM seed leak 'tip of the iceberg'". BBC News Online, 24/5 – 2000. http://news.bbc.co.uk/hi/english/sci/tech/newsid_762000/762254.stm
9 Nuffield Council in Bioethics (1999), p. 91

imposed on them (theoretical consideration: even small uncertainties (with associated risk perceptions) lead to large resistance when there is nothing gained)

Regulation

- Risk assessment/hazard identification: product or process?
  1. Product: only the finished GM food product is evaluated, in terms of 'substantial equivalence' with conventional counterpart (OECD definition). Micro-level of analysis (chemical composition).
  2. Process: each GM food product is evaluated on a special basis in terms of the specific process by which it is made (there are several different in rDNA technology). Macro-level of analysis (ecological effects). Also: societal effects. Reference: Jasanoff (1998)
- Burden of evidence: on perpetrator or victim? Reference: ESRC (1999)

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Additional material

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